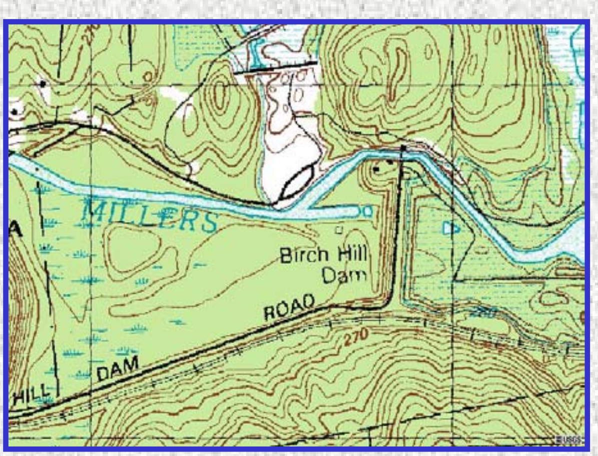
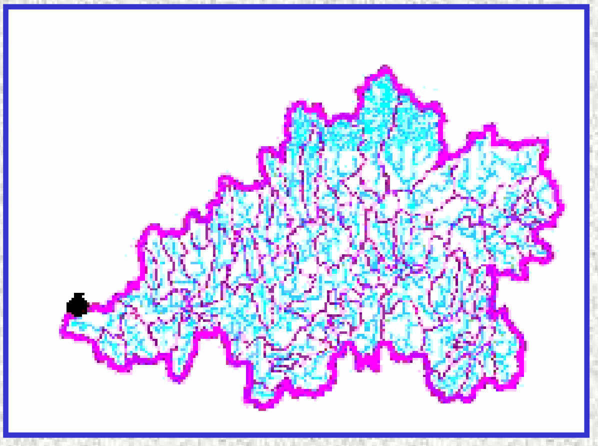
Massachusetts Department of Environmental Management

Hydrologic Assessment of the Millers River





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Executive Summary

ES1.0 Introduction

In 1994, Massachusetts embarked on a new approach to environmental management- the Watershed Initiative. The Watershed Initiative is a broad partnership of state and federal agencies, conservation organizations, businesses, municipal officials and individuals. The Initiative is an innovative, results-oriented program that protects and restores natural resources and ecosystems on a watershed basis. Watershed Teams, such as the Millers River Watershed Team, were created with the goal of understanding watersheds and improving the overall health of the ecosystem. This study was prepared for and funded by the Massachusetts Executive Office of Environmental Affairs, on behalf of the Millers River Watershed Team, as part of the Massachusetts Watershed Initiative.

The purpose of this project is to provide a comprehensive assessment of the current and potential impacts that human activities in the Millers River Basin have on flow-dependent natural resources. There are numerous human activities in the Millers River Basin that affect the timing, magnitude, frequency, and rate of change of natural flows in the Millers River and its tributaries including:

- public and industrial water supply withdrawals,
- wastewater and industrial discharges,
- operation of dams such as peaking hydroelectric facilities, or seasonal storage reservoirs such as flood control facilities, and,
- long-term land use changes.

To support the overall goal of this project, various hydrologic records (water withdrawal records, wastewater discharge records, United States Geological Survey (USGS) streamflow records) were collected and evaluated to understand the magnitude, duration and timing of flow conditions in the Millers River Basin. Once the hydrologic records were evaluated, and the interrelationships between the human activity and regulated streamflow were determined, the resulting potential impacts on natural/biological resources were evaluated.

Opportunities exist to improve aquatic habitat in the Millers River Basin by better management of river flow. Even modest modifications toward the natural flow regime (such as maintaining run-of-river operation, flushing flows, ramping rates, and seasonal minimum flows below dams) may result in vast improvements in aquatic habitat conditions in the Millers River.

ES2.0 Watershed Description

The Millers River watershed is located in north central Massachusetts and southwestern New Hampshire where it is bordered on the east by the Nashua River Basin, the south by the Chicopee River Basin, and on the west by the Connecticut River Basin. Shown in Figure ES2.0-1 is a basin map of the Millers River. Also shown in Figure ES2.0-2 is a nodal diagram showing the key locations of dams, flow gages, and wastewater treatment plant discharges (note this map is not to scale). The Millers, Deerfield, Chicopee and Westfield Rivers are the four major tributaries of the Connecticut River in Massachusetts. The Millers River begins at the outlet of Sunset Lake in Ashburnham. The mainstem is joined by the North Branch Millers River at Whitney Pond in Winchendon. From its origins in New Hampshire it flows south and then gradually turns west to the Connecticut River. The Millers River flows for approximately 51 miles, 44 miles of which occur in Massachusetts. The watershed drains a total of 389 square miles (mi^2), approximately 310 mi^2 of which are in Massachusetts. The major tributaries to the Millers River include the Otter (60.4 mi^2) and Tully Rivers (74.0 mi^2).

Parts or all of the following towns are located in the Massachusetts portion of the basin: Erving, Montague, Wendell, New Salem, Northfield, Warwick, Orange, Royalston, Athol, Petersham, Phillipston, Templeton, Winchendon, Hubbardston, Westminster, Ashburnham, and Gardner. The towns are generally rural and land use in the Massachusetts portion of the watershed is over 81% forested.

ES3.0 Dams in the Millers River Basin

The Millers River Basin has over 197 dams that are used for various purposes including water supply, hydropower generation, industrial use, fire protection, flood storage, and recreation. Most of the dams were constructed many years ago having provided water and power for the region's industrial growth. This report evaluated dams on the mainstem of the Millers River, and on larger tributaries including Tully, Otter and the North Branch Millers River.

Most of the mainstem dams are equipped with hydropower turbines to produce electricity. In addition to these, there are numerous other dams along the Otter River, Tully River and the smaller tributaries to the Millers River Basin. The US Army Corps of Engineers (Corps) operates two flood control projects in the Millers Basin, Birch Hill Dam on the Millers River in South Royalston and Tully Dam on the East Branch Tully River north of Athol.

Mainstem Dams (non-Corps)

Most of the mainstem hydroelectric stations are exempt from the Federal Energy Regulatory Commission (FERC) relicensing process. Dam owners (called Licensees) that are under FERC jurisdiction are required to conduct a National Environmental Policy Act (NEPA) analysis to determine the affects of project operations on various resources (aquatic, biological, wildlife, botanical, etc). When FERC grants an exemption, the Licensee must accept the operational conditions (minimum flows, project operating conditions, etc) recommended by the Federal (United States Fish and Wildlife Service, USFWS) and state (Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement, MDFWELE) fish and wildlife agencies. For the FERC exempt dams on the Millers River, the federal and state agencies mandated run-of-river operations, whereby reservoir inflow should instantaneously equal reservoir outflow. In addition, for those dams that bypass segments of the river, minimum flow requirements were mandated in the bypass reaches. Although the exempt facilities on the Millers River (except the Birch Hill Dam) are to be operated as run-of-river facilities, an evaluation of year 2000 hourly flow records suggest otherwise. Flow gages below some mainstem dams show flow fluctuations of 50-60 cubic feet per second (cfs) in one day, reflecting store-and-release type operations. At the New Home Dam in Orange, discharges have fluctuated up to 80 cfs, twice a day. Trout Unlimited (TU) has brought the pulsing operation at New Home Dam to the regulators' attention and discussions are ongoing to resolve this issue.

Corps Dams (FERC-exempt Projects)

To reduce potential flooding, similar to the devastation suffered by communities bordering the Millers River during the November 1927, March 1936 and September 1938 floods, the Corps constructed two flood control facilities in the Millers River Basin. Tully Lake Dam is operated as a seasonal storage reservoir by increasing discharges in the fall to create storage for the spring runoff. Birch Hill Dam, a dry-bed reservoir, also functions to store spring flows. These facilities serve a vital function of providing flood protection; however, operations at these flood control projects result in altering the natural timing, magnitude, frequency and rate of change of flow in the East Branch Tully River and the Millers River (below South Royalston). Changes to the natural flow regime caused by these projects include: a) the seasonal distribution and timing of flows, b) the magnitude of low and high flows, and c) the rate of flow change (as gate changes can occur abruptly over minutes). As of September 2002, the Corps and USFWS are having discussions relative to how the Corps operates both facilities. Discussions have focused on project operations including: a) the magnitude of flow releases for pre-scheduled whitewater races, b) the rate of flow change- ramping rates, and c) maintaining minimum flows.

It is recommended that discussions between the agencies and the Corps continue. The goal is to operate the facilities closer to a natural system (establish perhaps seasonal minimum flows, limit the rate of flow change, etc), while still serving the primary purpose of flood control.

ES4.0 Current and Projected Water Supplies

Six communities in the Millers River Basin are registered and/or permitted under the Massachusetts Water Management Act (WMA) to withdraw[1] water either from groundwater wells or surface water reservoirs for public water supplies. In addition, there are four registered/permitted industrial water users, although only two are currently active as of September 2002. Shown in Table ES4.0-1 are the WMA water users and their allowable withdrawal.

Table ES4.0-1: Water Management Act: Registered and Permitted Water Withdrawals in the Millers River Basin (>100,000 GPD or 0.1 MGD)

Name	Authorized Average Daily Withdrawal in 2000 (MGD)
Public Water Suppliers	
Ashburnham Water Department	0.18
Athol Department of Public Works- Water Division	1.04
Gardner Department of Public Works- Water Division	1.69
Orange Water Department	0.93
Templeton Water Department	0.84
Winchendon Water Department	0.67

[1] The study examined only water withdrawals exceeding 0.1 MGD or 100,000 gallons/day.

Name	Authorized Average Daily Withdrawal in 2000 (MGD)
TOTAL: Public Water Suppliers	**5.35 MGD**
Industrial Water Users	
American Tissue Mills of Mass., Inc.	2.02 (inactive as of 9/1995)
Erving Paper Mills	2.66
International Paper Company-Strathmore Millers Falls Facility	0.75 (inactive as of 8/2000)
Seaman Paper Co. of MA, Inc	1.19
TOTAL: Industrial Users	**6.62 MGD**
TOTAL BASIN WIDE Average Daily Withdrawal	**11.97 MGD**

Water withdrawals can affect river flows between the point of withdrawal and the return flow location, typically a wastewater treatment plant. The result of water withdrawals is a reduction in the magnitude of flow below the withdrawal point, which can affect the aquatic resources downstream. Of particular concern is the magnitude of withdrawal relative to the magnitude of river flow, particularly during the summer when river flows are typically low. Increased summer withdrawals needed to meet peak demand can reduce the amount of aquatic habitat and potentially create poor water quality conditions (low dissolved oxygen and increased water temperature).

As a whole, the majority of water withdrawals are eventually returned to the same Millers River Basin via wastewater treatment facilities or septic systems, thus there is only a minor loss of water from the basin. Only the Ashburnham Water Department sends a minor portion of their withdrawal out of the Millers River Basin, as the town of Ashburnham straddles the Millers River and Nashua River watershed divide.

Each public water supplier in the Millers River Basin was evaluated in terms of the average residential daily consumption (gallons per capita day, gpcd), unaccounted-for-water, and status of water conservation plans. The state has two metrics used to evaluate water suppliers- limit residential water use to 70-80 gpcd and limit unaccounted-for-water (UAW) to 10%-15% of the total water supply. For the six public water suppliers in the Millers River Basin, five have exceeded the 10% UAW metric at some point in the last three years. In most cases, water suppliers explained the high UAW was the result of leaks, fire flow, etc. All water suppliers reported residential water use as less than 80 gpcd.

Future water demands in the basin were estimated for each public water supplier based on the previous three years of withdrawal data and forecasted population growth. Water demand in the basin is expected to increase, although the rate of growth appears manageable in this region of Massachusetts. To meet future demands, municipalities will have to consider a range of alternatives including implementing aggressive water conservation measures, increasing withdrawals at existing locations, adding new withdrawals, importing water, etc. The impacts of these potential withdrawal options would require further environmental evaluation. Shown in Table ES4.0-2 is the current basin-wide average daily demand, the forecasted demand, and the percent change through the year 2020.

Table ES4.0-2: Current Average Daily Demand, and Forecasted Water Supply Demands in the Millers River Basin 2005, 2010 and 2020.

Year	Current	2005	2010	2020
Demand (MGD)	5.28 MGD[2]	5.75 MGD	5.91 MGD	6.25 MGD
Net Difference relative to current demand	-	0.47 MGD	0.63 MGD	0.97 MGD
% Increase relative to current demand		8.8%	11.9%	18.4%

The net increase in demand between current and 2020 is 0.97 MGD appears manageable. As a basis for comparison, the 538 mi^2 Nashua River (located northeast of the Millers Basin) is forecasted to have a water supply demand increase of 4 MGD between current and 2020 (from 183 MGD to 187 MGD[3]).

Although additional water is needed to meet future demand, water conservation measures at existing public water suppliers require further evaluation. Water conservation plans are available for three of the six suppliers. In addition, those having water conservation plans are somewhat dated. It is recommended that all public water suppliers revisit their water conservation plans and identify ways of conserving water. After realistic water conservation measures are implemented and if water supplies remain short, municipalities should consider planning for developing future water supplies to meet projected demand.

It should be noted that industrial water use demands were not projected, as demand in this case is more a function of plant expansion. It is assumed that future industrial demands would continue according to their current registered and permitted rates.

ES5.0 Wastewater Discharges

The National Pollutant Discharge Elimination System (NPDES) is one of the principal mechanisms for eliminating water pollution under the Federal Clean Water Act (CWA). It mandates that wastewater dischargers can discharge waste into surface waters only if a NPDES permit is obtained. Within the Millers River Basin there are a total of 12 NPDES permits. This study examined only the NPDES discharge volumes; no evaluation of water quality was conducted.

For each permitted facility in the Millers River Basin, the average daily discharge per month was obtained for the period 1993-2001 and subsequently compared to the monthly average discharge limit. All of the dischargers were within their monthly discharge limit, except for the Winchendon Water Pollution Control Facility (WPCF), the Athol Wastewater Treatment Plant (WWTP) and the Orange WWTP. The Athol and Orange violations occurred in April and/or March, which coincide with the spring freshet. Stormwater inflow and groundwater infiltration to the sewer system may be causing the high discharge levels. Runoff from the Millers River Basin is typically high during this period, thus it is assumed that although the magnitude of discharge is in violation, proper dilution would likely occur. Alternatively, the Winchendon WPCF is in violation of the 0.50 MGD discharge limit for all months except July, August and September.

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[2] The current basin-wide average daily demand is less than the authorized withdrawal volume of 5.35 MGD.
[3] Source: Camp, Dresser, McKee Report: Hydrologic Assessment of the Nashua River Watershed, June 2002.

WWTP's typically follow a daily cycle, where water usage is highest in the morning and night. Treated effluent that is discharged to the river may follow a similar pattern as hourly flows may also cycle over a day.

ES6.0 Stressed Basins

The MDEM has developed guidelines to identify a basins stress level (low, medium and high) as summarized in a draft memo*: Stressed Basins in Massachusetts* (Office of Water Resources, February 26, 2001). The guidelines contain criteria shown in Table ES6.0-1 to determine a stream's stress classification (low, medium, or high). Stress levels are currently classified based only on the magnitude of streamflow. Other factors can affect river stress levels including poor water quality, loss of instream and riparian habitat, etc.

Table ES6.0-1. Massachusetts Stream Classification Criteria

Stress Classification	Criteria
High	Net outflow equals or exceeds estimated natural August median flow
Medium	Net outflow equals or exceeds estimated natural 7Q10 flow
Low	No net loss to the subbasin

To determine the stress classification, inflows and outflows to the subbasin must be quantified. Subbasin outflows consist of water withdrawals; while inflows consist of wastewater return flow. Using the approximate period 1993-2001, the net inflow or outflow was computed for certain subbasins in the Millers River Basin. The net inflow or outflow (in most cases outflow exceeded inflow) was then compared to the estimated natural[4] August median flow and 7Q10[5] flow (see Table ES6.0-1). The August median and 7Q10 flows were determined from the USGS' Streamstats Program. Using the criteria set forth in the guidelines, the stress levels were then determined for certain subbasins as summarized in Table ES6.0-2.

Table ES6.0-2: Stress Level Summary for Subbasins in the Millers River Basin

Subbasin Name	Drainage Area[a] (mi^2)	7Q10 Flow[a] (cfs)	August Median Flow[a] (cfs)	Stress Classification
Otter River	60.54 mi^2	1.91 cfs	11.6 cfs	Medium
Upper Naukeag Lake	1.90 mi^2	0.04 cfs	0.29 cfs	High
Tully River	72.80 mi^2	4.01 cfs	17.63 cfs	Low
North Pond Brook	1.98 mi^2	0.08 cfs	0.51 cfs	Medium
Millers River	388.87 mi^2	23.68 cfs	98.20 cfs	Low

The stress levels shown in Table ES6.0-2 should be considered only as flag for further evaluation. Several factors can affect the stress classification, including the method of computation. For example, by evaluating stress levels on larger basins, the impact of water withdrawals may be lessened. The Tully River basin contains three wells (Athol Water

[4] Natural means no sources of flow regulation or manipulation.
[5] "7Q10" means the lowest average flow rate for a period of 7 consecutive days with an expected recurrence interval of once in every 10 years.

Division) that withdraw water just upstream of the confluence with the Millers River. The Tully River drainage area at the confluence with the Millers River is 72.8 mi^2 and thus the magnitude of withdrawal relative to the drainage area is small—hence the stress level is low. However, if a smaller subbasin containing the three withdrawal locations were evaluated separately, the stress level could be determined as medium or high.

It should be also reiterated that the evaluation of stress is based solely on a few low flow statistics. The evaluation does not consider many other factors that play a role in river stress such as dam operations, water quality or instream habitat. For example, the stress level in a particular river reach may be considered low using the classification system, however, dam operations may result in a pulsing discharge where flows fluctuate considerably over a day, or water quality is considered poor. These factors could also change the stress level to either medium or high.

ES7.0 Hydrologic Evaluation

The United States Geological Survey (USGS) maintains several continuously recording stream gages in the Millers River Basin, some that are active and others that are retired. Shown in Table ES7.0-1 are the continuously recording USGS gages and Corps gages located in the Millers River Basin.

Table ES7.0-1: USGS and Corps Flow Gages Located in the Millers River Basin (Active and Retired)

Station Name	Drainage Area (mi^2)	Period of Record
USGS Gages		
Tarbell Brook near Winchendon, MA	17.8	6/1/1916-9/6/1983
Millers River near Winchendon, MA	81.8	6/5/1916-current
Priest Brook near Winchendon, MA	19.4	6/1/1916-current
Otter River at Gardner Rd, MA	20.0	7/1/1916-9/30/1917
Otter River at Otter River, MA	34.1	12/1/1964-9/30/1997 10/1/1998-9/30/1999
Millers River at South Royalston, MA	189.0	8/1/1939-10/31/1990
East Branch Tully River Near Athol, MA	50.5	6/13/1916-12/5/1990
Lake Rohunta Outlet near Athol, MA	20.3	12/1/1964-10/30/1985
Moss Brook at Wendell Depot, MA	12.1	6/1/1916-9/30/1982
Whetstone Brook at Wendell Depot, MA	5.22	12/18/1985-9/30/1991
Millers River at Erving, MA	372.0	7/1/1915-current
Corps Gages		
Millers River near Athol, MA	280.0	data provided for 2000
Outlet of Tully Lake Dam (Note lake elev. data is available)	50.0	Flow data available from USGS Gage on East Branch Tully River
Birch Hill Dam (Note: lake elev. data is available)	175.0	Flow data available from USGS gage on Millers at South Royalston

One of the goals of this study was to determine the impacts of human activities on the natural flow regime in the Millers River Basin. A tool used to identify the impact of human disturbance on the hydrologic regime is the Nature Conservancy's program "The Indicators of Hydrologic Alteration" (IHA). The IHA program assesses the degree of hydrologic alteration attributable to human influence within an ecosystem. The program evaluates 33 flow parameters to provide information on ecologically significant features of surface water regimes influencing aquatic, wetland and riparian ecosystems. The 33 flow parameters evaluate the timing, duration, frequency, magnitude and rate of change of flow conditions.

The IHA analysis was conducted on USGS gages in the Millers River Basin with 20 or more years of record. There are two key features of the IHA analysis that assist in identifying the effects of human disturbances on hydrologic regimes. First, the program allows users to compare pre-impact and post-impact hydrologic regimes- such as before and after the Corps Dams were constructed. Two USGS gages contain periods of record before and after the two Corps Dams were constructed- one gage located just below Tully Dam on the East Branch Tully River and a second gage located below both the Corps Tully Dam and Birch Hill Dams on the Millers River at Erving. A pre and post Corps dam analysis was conducted to determine how dam operations have changed the flow regime.

Many hydrologic systems experience a gradual, long-term accumulation of human impacts rather than a single impact such as a dam. To evaluate cumulative impacts, the IHA program has developed a trends analysis to determine if flows are generally increasing or decreasing over time. Most of the USGS gage flow records were evaluated using the trends analysis, as there was no single impact.

The findings of the hydrologic analysis are as follows:

- The operation of the Corps facilities has shifted the timing of naturally occurring fall and spring flows. The Corps reservoirs are drawn down in the fall in anticipation of the spring runoff. The drawdown/refill cycle has changed the timing and magnitude of flows over the fall and spring. Shown below is a summary table showing some of the larger changes in the magnitude of mean flow between pre and post Corps Dam conditions.

River Gage	October Mean Flow	March Mean Flow
East Branch, Tully River	Pre-Dam: 31.9 cfs Post-Dam: 43.7 cfs Difference: +11.7 cfs, +36.7%	Pre-Dam: 182.0 cfs Post-Dam: 134.3 cfs Difference: -47.7 cfs, -26.2%
Millers River at Erving	Pre-Dam: 292.9 cfs Post-Dam: 401.5 cfs Difference: +108.7 cfs, 37.1%	Pre-Dam: 1,231 cfs Post-Dam: 1,119 cfs Difference: -113 cfs, -9.1%

- The operation of the Corps facilities has significantly reduced the 1-, 3-, 7-, 30-, and 90-day annual maximum flow by storing large inflows. This is not surprising given that the purpose of the facilities is to reduce downstream flooding. For example, the 1-day pre and post dam maximum flows below Tully Dam are 859 cfs and 499 cfs, respectively, a considerable reduction. Similar trends were experienced at the Erving gage.

- The timing of the annual one-day maximum and minimum flow has also changed. For example, the timing of the minimum flow on the East Branch Tully River gage changed from September 9th under pre-dam conditions to August 21st under post-dam conditions, a shift of approximately 16 days. For the Erving gage, the annual 1-day minimum flow changed from September 23th under pre-dam conditions to August 28st under post-dam conditions, a shift of approximately 24 days. Larger shifts occurred for the annual 1-day maximum flow for the East Branch Tully River- from March 23rd (pre-dam) to May 6th (post dam), approximately 45 days later. Shifting the natural timing of high and low flows can affect the timing of certain life-cycle needs for various aquatic and riparian resources.

- Another change observed at the Millers River Erving gage is the rate of change- the rate of both rise and fall of the hydrograph. Whereas the rate of rise and fall (cfs/day) was greater (faster rise and fall rates) under pre-dam conditions, there is now less variability. The IHA program evaluates the fall and rise rates based on mean daily flows. A separate evaluation of hourly discharge records and reservoir elevations was conducted for the Corps facilities. Over shorter time intervals, there can be abrupt changes in discharge. For example, flow in the East Branch Tully River during August 2000 changed from 18 cfs to 350 cfs in 8 hours. The magnitude of these changes and the rate of rise are greater than a natural system.

- A review of hourly flow data during August and September 2000, a period of low flow conditions throughout the basin, showed that the Otter and Millers Rivers experience diurnal flow fluctuations. Fluctuations varied from having one cycle to two cycles a day. At the Millers River at Winchendon gage, there was a flow fluctuation of 6 to 7 cfs twice a day (when the total river flow was approximately 30 cfs). Similar pulsing flows were observed on the Otter River, where flows fluctuated by 2 cfs each day (when the total river flow was approximately 15 cfs). Pulsing flows were also observed at the Millers River in Athol (50-60 cfs fluctuation each day) and on the Millers River in Erving (80 cfs fluctuation twice a day).

ES8.0: Impact of Human Manipulation on Aquatic Resources

Human activities in the Millers River Basin have resulted in changing the natural flow regime. The construction and operation of dams, water/industrial water supply withdrawals, wastewater discharges, and land use changes have the ability to regulate flows on the Millers River and its tributaries. Deviations from the natural timing, duration, magnitude and frequency of flows can affect riparian and aquatic resources. Based on the evaluation of gage flows, water withdrawals, and NPDES discharge flows, the potential impacts on aquatic resources resulting from flow regulation were identified. It should be noted that the potential impacts described below are general to all streams and rivers that experience similar flow conditions as the Millers River. No site-specific field data was collected as part of this study to further refine potential impacts.

Dams- Fish Passage

The Millers River Basin lies within the larger Connecticut River Basin, which has been subject to a long-term effort to restore Atlantic salmon[6]. Currently, adult salmon have upstream passage by several Connecticut River dams to the confluence of the Millers River. In the Millers River Basin, no upstream passage facilities for migrating adults have been mandated to date by the USFWS. However, the Millers River, between South Royalston and Athol, is stocked with salmon fry. After spending 2-3 years in freshwater, these salmon (now called smolts) migrate downstream in the spring to the ocean. Between the stocking location and confluence with the Millers River there are four dams in downstream to upstream order: New Home Dam, L.S. Starrett, Cresticon Lower and Cresticon Upper. Except for the L.S. Starrett Dam, all of the facilities are FERC-exempt, and are required to install fish passage facilities when mandated by the USFWS. As of September 2002, New Home Dam has downstream fish passage facilities on the north side of the dam, but not the south side. No downstream passage is provided at the L.S. Starrett Dam, however, the next two upstream facilities, Cresticon Lower and Cresticon Upper are fitted with downstream passage facilities. Thus smolts that migrate downstream in the spring have passage at three of the four dams. The efficiency of these downstream passage facilities for passing smolts is unknown.

Pulsing Flows

As discussed above, pulsing flows occur at various locations in the watershed including the Otter River, and the Millers River near Winchendon, Athol and Erving. Pulsing flows, depending on the magnitude of flow fluctuation, can have significant impacts on aquatic resources by causing fish and macroinvertebrate stranding, reducing available aquatic habitat and affecting spawning grounds.

Rate of Change (Up Ramping/Down Ramping)

As noted earlier all of the mainstem dams on the Millers River (except Birch Hill Dam) are to be operated where inflow instantaneously equals outflow. Thus the rate of rise and fall of the hydrograph should be the same above and below these facilities. The Corp's Tully and Birch Hill Dam facilities currently have no requirement on the rate in which discharges can be increased or decreased. Discharges at these facilities can change abruptly over a few hours, which can directly affect aquatic resources below the facilities (similar to the effects described above for pulsing flows). Implementing up and down ramping rates during non-flood periods would help to alleviate some of the potential impacts.

Flushing Flows

Flushing flows are deliberate high flow releases of short duration designed to mimic the effects of natural floods. The purpose of these high flow releases is to remove fine sediment accumulated on the bed (especially in spawning gravels), to maintain fish spawning and rearing habitat, and to maintain channel conveyance capacity. The Tully and Birch Hill Dam facilities were developed to reduce natural floods, however, there are instances when discharges are

[6] Strategic Plan of the Restoration of Atlantic salmon to the Connecticut River.

deliberately increased for the special whitewater events such as the River Rat race. It is unknown if these special discharges are sufficient to remove fine sediments from spawning gravels.

Seasonal Minimum Flows

Depending on the habitat characteristics and the species/life stage of native fish, adequate flows are necessary year-round to maintain habitat conditions in the river. Low flow conditions stress aquatic life and limit available habitat. These effects are most acute during low flow and poor water quality periods, such as the late summer.

For the Tully and Birch Hill Dams, currently year-round minimum releases of 10 cfs (0.20 cfsm) and 25 cfs (0.14 cfsm) are required, respectively. These minimum flow rates are lower than the seasonal minimum flows suggested by the USFWS in their New England Regional Flow Policy. Their Policy sets default minimum flows on a flow per square mile basis if no long-term USGS gage (reflecting unregulated conditions) or site-specific study has been conducted. The USFWS has designated the median August flow as the Aquatic Base Flow (ABF) [7]. The USFWS has assumed that the ABF will be adequate throughout the summer (at a minimum), unless additional flow releases are necessary for fish spawning and incubation.

To maintain a more natural hydrograph in the East Branch Tully River and the Millers River below the Corps facilities, minimum flows could be implemented on a seasonal basis. Based on the policy, the minimum flows for Tully and Birch Hill Dams would be higher than the current year-round minimum flow as shown in Table ES8.0-1.

Table ES8.0-1: USFWS New England Regional Flow Policy. Default Minimum Flows at Tully and Birch Hill Dams

Period	Fall/Winter (Oct-Mar)	Spring (Apr)	Summer (May-Sept)
Flow per square mile	1.0 cfsm	4.0 cfsm for the entire applicable spawning and incubation periods	0.5 cfsm as derived from the median August Flow
Tully Dam (50 mi^2)	50 cfs	200 cfs	25 cfs
Birch Hill Dam (175 mi^2)	175 cfs	700 cfs	88 cfs

For both the East Branch Tully River and the Millers River at Winchendon and Erving USGS gages, there is a period of record reflecting flow conditions prior to the Corps facilities being constructed. For the period 1917-1948 (32 years) the East Branch Tully River was unregulated, and thus the flow regime would represent near-natural conditions. Shown in Table ES8.0-2 is the median of the average monthly flows for both the East Branch Tully River and Millers River near Winchendon and Erving gages. For the East Branch Tully River gage the median August flow (ABF flow) for this period of record was 12.4 cfs or a flow per square mile of 0.25 cfsm (lower than the default ABF flow of 25 cfs -see Table ES8.0-1, but higher than the current minimum flow of 10 cfs).

[7] The ABF is derived from the median of the average August monthly flow records (per the New England Regional Flow Policy).

Although there is no completely unregulated period of flow record on the Millers River mainstem before the Corps facilities were constructed (since many dams were in place during the early 1900's), the Winchendon and Erving gages have lengthy pre-Corps dam periods of record worth investigating. The same analysis conducted above for the East Branch Tully River was applied to the Millers River at Winchendon and Erving gages for the period 1917-1940 (24 years). As noted above although the Corps facilities were not constructed during this period, other sources of upstream regulation occurred, but the level of regulation was likely less. Given this caveat the median August flow (ABF flow) at the Winchendon[8] and Erving USGS gages was 52.8 cfs (0.66 cfsm) and 173.9 cfs (0.47 cfsm), respectively[9]. Shown in Table ES8.0-2 is the median of the average monthly flows and flow per square mile for the three USGS gages.

Table ES8.0-2: Median of the Average Monthly Flows (cfs) and the Corresponding Flow per square mile (cfsm) for the East Branch Tully River and Millers River near Winchendon and Erving under Pre-Corps Dam conditions.

River/Period of Record	Median of the Average Monthly Flow in cfs (Pre-Corps Dams) & Flow per square mile in cfsm											
	Jan	Feb	Mar	Apr	May	Jun	Jul	**Aug**	Sep	Oct	Nov	Dec
East Branch, Tully River (1917-48), cfs	72.5	52.6	173.8	200.6	112.2	62.1	29.4	**12.4**	14.1	26.6	60.4	58.7
East Branch, Tully River (1917-48), cfsm	1.44	1.04	3.44	3.97	2.22	1.23	0.58	**0.25**	0.28	0.53	1.20	1.16
Millers River at Winchendon, MA (1916-40), cfs	122.4	125.8	259.4	366.9	155.6	92.6	63.1	**52.8**	51.2	57.1	89.6	109.2
Millers River at Winchendon, MA (1916-40), cfsm	1.50	1.54	3.17	4.49	1.90	1.13	0.77	**0.66**	0.63	0.70	1.10	1.33
Millers River near Erving, MA (1916-40), cfs	603.9	493.6	1,207	1,673	835.4	444.0	273.8	**173.9**	210.1	289.2	410.2	541.2
Millers River near Erving, MA (1916-40), cfsm	1.62	1.33	3.24	4.50	2.25	1.19	0.74	**0.47**	0.56	0.78	1.10	1.45

Based on Table ES8.0-2, the seasonal flow per square mile was computed for the three gages for comparison to the default flow per square mile (as shown in Table ES8.0-1). The cfsm values

[8] The Winchendon gage is located upstream of Birch Hill Dam. However, the same period of available record (1917-40) as the Erving gage was used for comparison purposes.
[9] The method of computing the ABF flow has varied among parties. The USFWS method computes the mean monthly flow, and then selects the median value from the array of annual August means. Another method relies on selecting the median flow value among all August average daily flows for the period of record. Using the second method results in minimum flows as follows: East Branch Tully River for period 1917-48- 9.6 cfs or 0.19 cfsm, Millers River at Winchendon for period 1916-40-54 cfs or 0.66 cfsm and the Millers River at Erving for period 1916-40- 166.0 cfs or 0.45 cfsm.

shown in Table ES8.0-3 were computed by selecting the lowest cfsm value for each season. For example, for the East Branch Tully River, the lowest flow per square mile during Oct-Mar occurred in October- 0.53 cfsm.

Table ES8.0-3: Summary of Seasonal Minimum Flows (on cfsm basis) based on New England Regional Flow Policy

River	Oct-Mar (Fall/Winter)	April (Spring)	May-Sep (Summer)
East Branch Tully River	0.53 cfsm	3.97 cfsm	0.25 cfsm
Millers River at Winchendon	0.70 cfsm	4.49 cfsm	0.66 cfsm
Millers River at Erving	0.78 cfsm	4.50 cfsm	0.47 cfsm
Default Values	1.00 cfsm	4.00 cfsm	0.50 cfsm

Exceptions to the seasonal minimums are likely warranted at the Corps facilities during flooding periods. For example, spring minimum flows could be reduced to help alleviate downstream flooding.

Besides dams, water withdrawals throughout the year also affect the timing and magnitude of flow in river reaches below withdrawal points. Because there is little water supply storage capacity in the Millers River Basin, water withdrawals occur throughout critical periods such as low flow conditions in the summer. The reduction in flow caused by withdrawals could have various effects such as: reduction in fish/macroinvertebrate habitat, increased water temperatures, and poor water quality.

Reservoir Operations

Tully Lake, Birch Hill Reservoir and other impoundments in the Millers River watershed have water levels that fluctuate. Changing water levels, beyond the natural cycle, can have an impact on an array of natural resources. For example, water levels in several impoundments including Tully Lake, Lake Monomonac, Lower Naukeag Lake and Sunset Lake are reduced in the fall and are refilled in the spring. The magnitude of drawdown varies (Tully Lake has a larger drawdown). Potential effects of a fall drawdown include a) fish spawning along the shoreline and the potential for exposure when the drawdown occurs, b) reservoir tributaries may be inaccessible for spawning fish, c) wetlands surrounding the impoundment could become dewatered and d) loss of aquatic vegetation and littoral zone feeding area (during the growing season). It is unknown if any of these potential impacts are present at those impoundments experiencing a fall drawdown.

ES9.0 Recommendations

Based on analyses conducted in this study, we have developed the following recommendations that could reduce the effects of human manipulations on streamflow and aquatic resources.

- It is recommended that all public water suppliers and industrial water users develop up-to-date water conservation plans to help reduce the need for increased withdrawals. Water suppliers should strive to maintain residential water consumption to 70-80 gpcd and limit unaccounted-for-water to 10-15%.

As described in the report, there are many instances where the reported residential water consumption or unaccounted for water (UAW) is inaccurately reported. For example, one water supplier showed residential water use as low as 26 gpcd. A value this low is likely inaccurate and is a function of how the population served is computed or estimated. Similarly, some water suppliers assumed that the water used for fire hydrant flushing or fire fighting as part of their UAW. According to MDEP, these sources are not considered UAW. It is recommended that reporting requirements for the population served and UAW be improved to allow the MDEP and others to better manage water supplies.

Although the forecasted water demands for the various public water suppliers in the region do not show a dramatic increase, it is recommended that municipalities initiate the planning process to identify solutions to meet future demands. In addition, there is limited storage capacity in the Millers Basin that could be used to meet peak demands during the summer, when river flows are low. Storage reservoirs would limit the need for increased summer withdrawals to meet peak demand and thus lessen the impact on streamflow and hence aquatic resources. An evaluation of the existing wastewater treatment facilities would also have to be considered to determine if the facilities can treat future increased waste loads.

- The study evaluated stress levels in the certain subbasins using the criteria developed by the State. The determination of stress level was based solely on low flow statistics. The evaluation does not consider many other factors that play a role in river stress such as dam operations, water quality or instream habitat. It is recommended that further information on water quality, instream aquatic habitat, etc be collected and evaluated within those subbasins flagged as medium or high stressed. Future withdrawals should be avoided in these areas and mitigation of current impacts should be evaluated.

- It is recommended that the FERC-exempt mainstem dams (excluding the Birch Hill Dam) comply with USFWS requirements to operate the facilities as run-of-river. New Home Dam, the lowermost dam is currently in the process of rectifying the pulsing flows below their project with the FERC. In addition, pulsing flows were observed in the 2000 hourly hydrographs in the Otter River and in the Millers River near Winchendon and Athol. It is difficult to pinpoint what human activity is causing the pulsing flows; however, further investigation is recommended. The goal is to reduce the artificial pulsing that has historically occurred to match a natural cycle.

  To ensure run-of-river operations it is recommended that all dam operators install, calibrate and maintain a continuous streamflow monitoring gage. It is recognized that there is a substantial cost to install and maintain a streamflow monitoring gage, so further discussions with dam operators is warranted to determine other methods to demonstrate compliance with run-of-river operations.

- This study evaluated hourly flow data for the period August 22 to September 16, 2000, which showed pulsing flows. The report speculated the cause or causes of pulsing flows, however, additional information could help better pinpoint the source. It is recommended that the following data be collected and evaluated, if available:

- Hourly or daily *water elevation* records for all dams on the Millers River mainstem, Otter River Dam, and Tully Lake Dam. These data could be used to confirm which facilities are operating in a run-of-river manner.
- Hourly or daily *discharge* records for all dams on the Millers River mainstem, Otter River Dam and Tully Lake Dam (broken down by turbine flow, gate flow, dam spillage, etc.). The discharge records would be used to determine if the dams are pulsing discharges.
- Hourly or daily discharges for all NPDES facilities discussed in this report should be evaluated. Again, hourly or daily discharge data would be used to determine what effect discharges have on streamflow.

Overall, there needs to be a more coordinated operation of dams on the Millers Rivers and its tributaries to ensure that all pulsing operations are ceased.

- As noted above there are approximately 197 dams in the Millers River Basin. Some of these dams were constructed in the early 1900's for use as grist mills, sawmills, or textile manufacturing. Since many of these dams are likely abandoned and serve no purpose, consideration should be given to potential dam removal. This study did not consider the costs and benefits of potential removal. In most cases feasibility studies are conducted to determine the pros and cons of potential removal. River Restore in Massachusetts and the New Hampshire Department of Environmental Services in New Hampshire have been actively involved in dam removals in their respective states.

- Section 6.0 of this report evaluates discharges from wastewater treatment plants in the basin that have NPDES permits. Absent from that discussion is an evaluation of two water treatment plant dischargers including Gardner Water Treatment Facility (MAG640041) and the Ashburnham/Winchendon Joint Water Authority (MAG640045). The initial evaluation focused only on the WWTP discharges. However, it is recommended that additional analysis of the water treatment plant discharges are warranted to provide a complete picture of flow management in the basin. More specifically, hourly or daily records of discharges from these two facilities are needed to evaluate the impact on receiving waters.

- The Corps and USFWS are currently in the process of discussing the operation of Tully and Birch Hill Dams. These projects have the largest impact on the timing, magnitude, duration and frequency of flows in the East Branch Tully River and the Millers River below South Royalston. It is recommended that discussions continue and that the following flow-related issues be resolved: a) seasonal minimum flows, b) flushing flows, c) special whitewater releases, and d) up and down ramping rates. The goal is to operate the facilities to mimic the natural runoff cycle, while preserving the purpose of the facilities to reduce flood flows.

- To facilitate salmon smolt migration to the ocean, downstream fish passage may be warranted at the L.S. Starrett facility (although the USFWS does not have authorization to require passage). Continuous downstream passage would then be provided between the stocking location and the Connecticut River.

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Acronyms, Conversions, Glossary of Terms

Acronyms

ABF	Aquatic Base Flow
ADPW	Athol Department of Public Works- Water Division
AWD	Ashburnham Water Department
cfs	cubic feet per second
cfsm	cubic feet per second per square mile of drainage area
COE	United States Army Corps of Engineers
Corps	United States Army Corps of Engineers
CWA	Clean Water Act
DMR	Discharge Monitoring Report
EOEA	Executive Office of Environmental Affairs
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
FOIA	Freedom of Information Act
GDPW	Gardner Department of Public Works
GIS	Geographic Information System
GP	Gravel Packed (as in Gravel Packed Well)
gpcd	gallons per capita day
GPD	gallons per day
GW	groundwater
GS	Gomez and Sullivan Engineers, P.C.
IHA	Indicators of Hydrologic Alteration
IP	International Paper
lbs/day	pounds per day
MA-GIS	Massachusetts Geographic Information System
MDEM	Massachusetts Department of Environmental Management
MDEP	Massachusetts Department of Environmental Protection
MDFWELE	Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement
MG	million gallons
MGD	million gallons per day
mg/l	milligrams per liter
MGL	Massachusetts General Law
MGM	million gallons per month
MGY	million gallons per year
mi^2	square miles
MODS	Massachusetts Office of Dam Safety
NHDES	New Hampshire Department of Environmental Services
NGVD	National Geodetic Vertical Datum
NPDES	National Pollutant Discharge Elimination System
OWD	Orange Water Department
PCB	Polychlorinated Biphenyls
PCS	Permit Compliance System

PWSASR	Public Water Supply Annual Statistical Report
RRT	Reservoir Regulation Team
TU	Trout Unlimited
SPC	Seaman Paper Company
SW	surface water
USACOE	United States Army Corp of Engineers
USGS	United States Geological Survey
WeWD	Westminster Water Department
WWD	Winchendon Water Department
WWTP	Wastewater Treatment Plant

Conversions

1 MGD=1.547 cfs
1 MGD= 1,000,000 GPD
1 acre= 43,560 square feet
1 mi^2= 640 acres

Glossary of Terms

cfs (cubic feet per second) : The flow rate or discharge equal to one cubic foot (of water, usually) per second. This rate is equivalent to approximately 7.48 gallons per second. This is also referred to as a second-foot.

cfs-day : The volume of water discharged in twenty four hours, with a flow of one cubic foot per second is widely used; 1 cfs-day is 24 x 60 x 60 = 86,000 cubic feet, 1.983471 acre-feet, or 646,317 gallons. The average flow in cubic feet per second for any time period is the volume of flow in cfs-days.

Discharge: the volume of water that passes through a given cross section per unit time. Discharge is commonly measured in cubic feet per second (cfs) or cubic meters per second (cms). It is also referred to as *flow*.

Exceedence probability: hydrologically, the probability that an event selected at random will exceed a specified magnitude.

Flood Frequency Curve: (1) A graph showing the number of times per year on the average, plotted as abscissa, that floods of magnitude, indicated by the ordinate, are equaled or exceeded. (2) A similar graph but with recurrence intervals of floods plotted as abscissa.

Flow Duration Curve: A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Frequency Curve: A curve that expresses the relation between the frequency distribution plot, with the magnitude of the variables as abscissas and the number of occurrences of each magnitude in a given period as ordinates. The theoretical frequency curve is a derivative of the probability curve.

Hydrograph: a description of flow versus time or a description of stage versus time.

Hydrology: the study of water. Hydrology generally focuses on the distribution of water and interaction with the land surface and underlying soils and rocks.

Instream use: The use of water that does not require withdrawal or diversion from its natural watercourse; for example, the use of water for navigation, recreation, and support of fish and wildlife.

Interbasin Transfer: The physical transfer of water from one watershed to another.

Peak flow: the point of the hydrograph that has the highest flow.

Pulsing flow: the artificial increase and decrease of flow that typically follows a daily pattern.

Rating curve: the relationship between stage and discharge.

Reach: a segment of a stream channel.

Recurrence Interval: The average amount of time between events of a given magnitude. For example, there is a 1% chance that a 100- year flood will occur in any given year.

Reservoir: A manmade facility for the storage, regulation and controlled release of water.

Reservoir Surface Area: The surface area of a reservoir when filled to the normal pool or water level.

Reservoir Volume: The volume of a reservoir when filled to normal pool or water level.

Runoff: That part of precipitation that flows toward the streams on the surface of the ground or within the ground. Runoff is composed of baseflow and surface runoff.

Run-of-River Operation: A reservoir is operated as a run-of-river facility when reservoir inflow instantaneously equals reservoir outflow. There is no change in the timing or magnitude of reservoir inflow or outflow.

River Gage: A device for measuring the river stage, via a rating curve, river flow.

Stormwater Discharge: Precipitation that does not infiltrate into the ground or evaporate due to impervious land surfaces but instead flows onto adjacent land or water areas and is routed into drain/sewer systems.

U.S. Geological Survey (USGS): The Federal Agency chartered in 1879 by congress to classify public lands, and to examine the geologic structure, mineral resources, and products of the national domain. As part of its mission, the USGS provides information and data on the Nation's rivers and streams that are useful for mitigation of hazards associated with floods and droughts.

Watershed: an area characterized by all direct runoff being conveyed to the same outlet. Similar terms include *basin*, *subwatershed*, *drainage basin*, *catchment*, and *catch basin*.

Wetland: An area that is regularly wet or flooded and has a water table that stands at or above the land surface for at least part of the year.

1.0 Introduction

The Executive Office of Environmental Affairs Watershed Initiative- Millers River Basin Team- commissioned a study to conduct a hydrologic assessment of the Millers River Basin. The Millers River basin is located in north central Massachusetts and southwestern New Hampshire. It has a drainage area of 389 square miles (mi^2), and flows in a general western direction before emptying into the Connecticut River.

The purpose of this project is to provide a comprehensive assessment of the current and potential impacts of water withdrawals on water- and flow-dependent natural resources by preparing an inflow/outflow analysis (watershed water budget) for the Millers River Basin. To support the overall goal of this project, various hydrologic records were collected and evaluated to understand the magnitude, duration and timing of flow patterns in the Millers River Basin. The various hydrologic records that were evaluated as part of this study were key factors in identifying river reaches that were potentially stressed by human activities such as water withdrawals, pulsing hydropower releases, dam operations, and wastewater treatment plant discharges. Highlighted in the bullets below were the key hydrologic parameters that were analyzed in determining the impacts of regulated streamflow on aquatic resources.

- Information was gathered on all registered and permitted water withdrawals in the Millers River Basin (both industrial and public water supply withdrawals that withdrawal greater than 100,000 gallons per day) to understand the timing and magnitude of withdrawals. There are currently six water supply companies and four[10] industrial water withdrawals in the basin. Graphs were developed to identify trends in annual and seasonal water demands for the period 1993-2000. In addition, the river reaches affected by water withdrawals were identified- this required identifying the water withdrawal location as well as the location of return flow to basin via wastewater treatment plant facilities or other means. Lastly, using census data and public water supply reports, water supply demands were projected into the future - 2005, 2010 and 2020. These projections assisted in identifying river reaches that could be further stressed.

- Data was gathered on all National Pollutant Discharge Elimination Systems (NPDES) dischargers in the Basin. NPDES permits are currently available for twelve facilities in the basin. The location of all NPDES dischargers were placed on a basin map to understand where recharge to the receiving river occurred. The permitted monthly average discharge was compared to the observed monthly discharge data to determine if the NPDES dischargers were in compliance with their permit.

- Information was collected on all dams in the Millers River Basin, including dams located in Massachusetts and New Hampshire. There are approximately 197 dams in the basin, with eight dams located on the Millers River mainstem; one of these dams is the US Army Corps of Engineers (Corps) Birch Hill Dam. The Corps also has a flood control facility on the East Branch Tully River. The mainstem dams and Corps facilities were evaluated at a higher level than the majority of smaller dams in the basin as the larger facilities have a greater

[10] Two of the four industrial users were not operating as of March 2002.

capacity to regulate river flow. Evaluating all 197 dams is beyond the scope of this study. Information was collected on how the major dams are operated by placing telephone calls to owners, or researching available data on the Federal Energy Regulatory Commission's (FERC) website (this applies only to the FERC exempt projects). The use of historic flow records were used to determine if the operation of major dams in the basin affected the timing and magnitude of flows in the Millers River, as well as two of its larger tributaries- the Tully and Otter Rivers.

- There are several United States Geological Survey (USGS) gages as well as Corps maintained gages in the Millers River Basin that measure river stage and hence flow. Numerous flow statistics were developed from the available flow records including: annual hydrographs, hourly hydrographs, flood frequency analysis, and low flow frequency statistics. In addition to evaluating existing conditions, the USGS's Streamstats Program[11] was utilized to estimate low flow statistics assuming an unregulated river system. Thus, comparisons between regulated and unregulated low flow statistics could be developed. The purpose of this exercise was to determine how human activities have affected streamflow in the Millers River.

- The Indicators of Hydrologic Alternation (IHA) program, supported by the Nature Conservancy, was applied to each of the USGS gages in the basin. The IHA program generates 33 hydrologic parameters using mean daily flow data. For this project the program was used in two fashions. First, a comparison of the 33 hydrologic parameters was developed for pre- and post-Corps Dam USGS gages on the East Branch Tully River and on the Millers River at Erving. Secondly, for the remaining gages, where there was no discrete human disturbance (such as dam construction), but rather a long-term accumulation of human activities, the IHA program was operated in the "trends" mode, to determine any long-term trends in the 33 hydrologic parameters.

The hydrologic analysis of WMA registered/permitted water withdrawals, NPDES discharge data, and USGS gage flow data was conducted to identify and quantify the impact of human activities in the Millers River Basin on streamflow and aquatic resources. Many of the human activities have resulted in changes to the frequency, magnitude, duration and timing of flows, which can directly impact fish and aquatic life, riparian habitat, and other natural resources. For example, a review of hourly hydrographs during August/September 2000 showed that the Millers River in Athol is fluctuated by as much as 50-60 cfs within a day. Other river locations experience two fluctuations within a 24-hour period where flows rise and fall by as much as 80 cfs. In addition to pulsing flows, the operation of the flood control facilities has changed the natural seasonal streamflow pattern in the Millers River experienced in the fall and spring, although it is understood that the purpose of these facilities is to limit flooding along the Millers and Connecticut Rivers.

There are numerous impacts that these human activities can have on aquatic resources that utilize the river. Although discussed in more detail later in this report, some of the potential impacts identified (this is not a full list) include:

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[11] The USGS Streamstats program is a tool that estimates low flow statistics at any river location in Massachusetts assuming an unregulated river system.

- continually shifting fish and macroinvertebrate habitat resulting from pulsing hydropower operations and wastewater treatment plant discharges,
- pulsing flows affect riparian habitat along the stream margin,
- potential fish stranding in pools located along the river's edge when flows are pulsed,
- inability of some species, such as macroinvertebrates, to quickly respond to rapid flow changes (macroinvertebrates are essentially an immobile species incapable of physically moving fast enough to remain inundated when flows are pulsed),
- a reduction in the magnitude of flow may impact certain river reaches, where water withdrawals for public water supply system or industrial use occurs, and
- the reduction of peak flows due to the Corps operations can reduce spring flushing flows, which are needed to clean gravel substrates utilized by spawning fish and inundate habitats utilized by wildlife.

It should be noted that this study was a desktop exercise; no field data was collected to determine how the manipulation of water specifically impacts aquatic resources. Certain reaches of the Millers River may provide greater habitat quality and thus the impact of human activities may be more severe. Further field reconnaissance and study are needed to clearly identify the most affected reaches.

In addition to understanding the impacts of human activities, general information on the Millers River's basin characteristics were evaluated. Numerous geographic information system (GIS) maps of the basin were developed to depict land use, surficial geology, average annual precipitation, and topography. This evaluation focused on the Massachusetts portion of the Millers River Basin, while only cursory information on the New Hampshire portion of the basin was provided in the study.

It should be noted that there are numerous figures and tables associated with this document. For those tables or figures not appearing within the text, a separate bound document has been developed (rather than placing the graphs at the end of each section of the report). By developing a separate table/figure document, readers can read the text and observe the figures/tables at the same time.

2.0 Millers River Basin Description and Characteristics

2.1 General Overview of the Millers River Basin

The purpose of this section is to provide an overview of the Millers River Watershed characteristics (climate, geology, land use) and to describe various components of the river's course. The Millers River watershed is located in north central Massachusetts and southwestern New Hampshire where it is bordered on the east by the Nashua River, the south by the Chicopee River, and on the west by the Connecticut River Basin as shown in Figure 2.1-1. The confluence of the Millers River with the Connecticut River is in Erving. The Millers, Deerfield, Chicopee and Westfield Rivers are the four major tributaries of the Connecticut River. The Millers River is formed at the outlet of Sunset Lake in Ashburnham. From its origins in New Hampshire it flows south and then gradually turns west flowing into the Connecticut River. The Millers River flows for approximately 51 miles, 44 miles of which occur in Massachusetts. The watershed drains a total of 389 square miles (mi^2), approximately 310 mi^2 of which are in Massachusetts. The major tributaries to the Millers River include the Otter (60.4 mi^2) and Tully Rivers (74.0 mi^2).

There are a total of 101 lakes and ponds in the Millers River Basin, 72 of which have an area of 10 acres or more. Only one lake, Lake Monomonac in Winchendon (592 acres), is larger than 500 acres (Source: USGS website).

Ten dams on the mainstem, and two on the North Branch supply flood control, hydropower generation or serve recreation needs. In addition, there are numerous other dams along the Otter River, Tully River, and the smaller tributaries within the Millers River Basin.

Parts or all of the following towns are located in the Massachusetts portion of the Millers River Basin: Erving, Montague, Wendell, New Salem, Northfield, Warwick, Orange, Royalston, Athol, Petersham, Phillipston, Templeton, Winchendon, Hubbardston, Westminster, Ashburnham, and Gardner.

2.2 Detailed Description of the Millers River, Otter River and Tully River Courses

Millers River

The headwaters of the Millers River are formed by numerous ponds in Rindge and New Ipswich New Hampshire on the North Branch as shown in Figure 2.2-1. The North Branch joins the mainstem at Whitney Pond Dam in Winchendon Center. From the outlet of Whitney Pond the river flows west through a short stretch of rapids to another small impoundment, Hunts Pond Dam, near the intersection of Routes 12 and 202. After Hunts Pond Dam the Millers River continues west through more rapids passing under Route 202 to Tannery Pond Dam. After Tannery Pond Dam, the river slows, becomes deeper, and then turns north until reaching the Winchendon Wastewater Treatment Plant (WWTP). The river then turns south continuing to exhibit somewhat sluggish flow as it passes through a massive flat area which is part of the Birch Hill Flood Control Project. Before leaving this area the river turns west and joins with the Otter River. This sluggish segment ends at Birch Hill Dam, one of two flood control dams in the basin built by the Corps.

After flow is discharged from Birch Hill Dam, it becomes swifter just above Route 68 in South Royalston. The river begins a southwest course fluctuating between rapids and semi-uniform flow. For the next five miles the river flows through a largely undeveloped area dropping over 225 feet. This stretch is often referred to as "The Chute". The flow is then impounded by the dam at the old Union Twist Drill Company in Athol, called L.P. Athol Dam. There are two impoundments in succession- Cresticon Upper Dam and Cresticon Lower Dam. After passing a short rapid section the flow again becomes impounded at the L. S. Starrett Company Dam (Crescent Street Dam). The river flows west to its confluence with the Tully River, then southwest, passing under Route 2A to the Athol-Orange town line where it continues in a northwest direction to New Home Dam in Orange Center.

From New Home Dam the next 10.5 miles of river flows swiftly, passing Erving Paper and the Erving Center WWTP. The river then flows through the Village of Millers Falls where it receives the effluent from the Erving POTW#1. It then flows past the old dam at Route 63 and a short distance farther before entering the backwater of the Connecticut River in Gill.

Otter River
The headwaters of the Otter River originate in the wetland areas of Hubbardston, Templeton, and Gardner. The river slowly meanders through the marshy areas of Gardner passing under Routes 2 and 2A where it receives the effluent from the Gardner WWTP. It then flows under Route 101 and meanders past sand and gravel operations before entering the impoundment at Seaman Paper Company. The paper company's treatment plant discharges a short distance below the dam. The river enters a short rapid section before entering another impounded area formed by the partially breached dam at the old Baldwinville Products Mill. Just below the old dam the Templeton WWTP discharges to the river. The river velocity increases as it flows through Baldwinville passing under Route 68. The river then enters the wetlands in the Otter River State Forest continuing for three miles before emptying into the Millers River.

Tully River
The East Branch Tully River begins in Richmond, New Hampshire, entering Massachusetts in Royalston. The river flows south through wetlands to Tully Lake created by Tully Dam. This impoundment is part of the second flood control project built and operated by the Corps in the Millers River Basin. After leaving the reservoir the velocity increases as the river flows south to Athol where it joins the West Branch Tully River. The West Branch originates in Warwick, Massachusetts as a mountain stream. It flows south to Sheomet Lake. Leaving the lake it flows swiftly southeast through the corner of Orange and into Athol where it joins the East Branch. The Tully River then flows slowly through wetlands emptying into the Millers River just north of Routes 2A and 202 in Athol.

2.3 Basin Topography and River Slope

Shown in Figure 2.3-1 is a topographic relief map of the Millers River Watershed. The terrain through the Millers River corridor is best described as hilly. The highest terrain (elevations ranging from 450-610 feet) is located in the headwaters of the North Branch Millers River and in the headwaters of Scott/Priest Brook. River flow fluctuates from sluggish movement through flat areas of the basin such as near Birch Hill Dam, to areas where rapids occur due to elevation drops. Overall, the Millers River has a moderate gradient, averaging about 18 ft/mi from the headwaters area to the USGS streamflow gaging station at Erving, a distance of about 43 river miles. However, a five-mile reach of the Millers River (the Chute, which includes the section known as "the Bear's Den") through a wooded area between South Royalston and Athol has an average gradient of about 43 ft/mi, which is about five times the average for rivers in Massachusetts. A second 10.5-mile reach of river rapids begins in Orange, passes through Erving, and ends in Millers Falls. A profile of the Millers River elevation versus river mile is shown in Figure 2.3-2.

2.4 Surficial Geology

A surficial geology map of the Millers River Basin is shown in Figure 2.4-1. Large quantities of unconsolidated sand, gravel, silt and clay form surface deposits that are underlain by bedrock. These deposits are capable of storing and transmitting large quantities of water. In fact, groundwater sufficient for domestic uses is available nearly everywhere in the basin (Source: USGS website).

Stratified glacial deposits in stream valleys form the best aquifers in the Millers River Basin. The largest area of glacial outwash was deposited in a glacial lake located near Orange. Meltwater streams deposited sediments, up to 200-ft thick, into this lake. Other areas capable of yielding moderate to large amounts of groundwater to wells occur near the mouth of the Millers River in Millers Falls, along the West Branch Tully River northwest of Athol, along the Otter River and Trout Brook, and in the Winchendon area (Source: USGS website).

2.5 Land Use

The land use in the Millers River Basin was determined from geographic information system (GIS) data provided by Mass-GIS as shown in Figure 2.5-1. The Massachusetts portion of the watershed is 81% forested, 6% open or farmland, 6% wetlands and 7% urban land (EOEA website). There are several large tracts of undeveloped land in the upper portions of the watershed. Various wildlife management areas are also established in the basin including:

- Birch Hill Wildlife Management Area 3,210 acres
- Millers River Wildlife Management Area 2,621 acres
- Wendell Wildlife Management Area 575 acres
- High Ridge Wildlife Management Area 2,049 acres
- Phillipston Wildlife Management Area 3,383 acres
- Popple Camp Wildlife Management Area 1,160 acres
- Tully Mountain Wildlife Management Area 332 acres
- Orange Wildlife Management Area 280 acres
- Fish Brook Wildlife Management Area 110 acres
- Lawrence Brook Wildlife Management Area 357 acres

The watershed encompasses all or part of 17 municipalities, and supports a population of approximately 87,000 people. The population centers are concentrated in Gardner, Athol and Orange, MA. The communities in the basin are largely rural, with some areas of moderate development. The New Hampshire portion of the basin (near Rindge, Jaffrey and Fitzwilliam) has several ponds, lakes and wetland areas. It should be noted that an analysis of New Hampshire land use was not part of the scope for this project.

2.6 Climate

It is important to understand the annual and seasonal distribution of precipitation in the Millers River Basin as it has a direct influence on the timing and magnitude of runoff. There are five long-term (at least 80 years of record) and one short-term (17 years) precipitation gage in the Millers River Basin as shown in Figure 2.6-1. Because of the basin's size, meteorological conditions can vary in different parts of the basin. For example, one portion of the basin may experience summer thunderstorms, while another portion of the basin might remain unaffected. Also higher elevations may receive more precipitation than lower elevations. Using the long-term precipitation gages, general statistics for each gage are summarized in Table 2.6-1.

Table 2.6-1 Precipitation Statistics at Gages Located in the Millers River Basin

	Precipitation Gages and Period of Record					
Statistic	Winchendon 1894-2001	Tully Lake 1984-2001	Athol 1912-2001	Templeton 1907-2001	Gardner 1906-2001	Fitzwilliam 1920-2001
Avg Ann Precipitation	43.03 inches/year	45.03 inches/year	42.75 inches/year	42.28 inches/year	43.38 inches/year	44.26 inches/year
Max Ann Precipitation	59.95 inches in 1938	58.66 inches in 1996	61.94 inches in 1972	65.90 inches in 1996	61.01 inches in 1938	56.92 inches in 1975
Avg Monthly Minimum Precipitation	2.94 inches in Feb	2.52 inches in Feb	2.79 inches in Feb	2.84 inches in Feb	3.12 inches in Feb	2.85 inches in Feb
Avg Monthly Maximum Precipitation	3.93 inches in Jul	4.70 inches in Aug	4.03 inches in Jul	3.96 inches in Jul	3.99 inches in Nov	4.07 inches in Jul
Maximum Monthly Precipitation	15.89 inches in Sep 1938	10.15 inches in Oct 1995	15.86 inches in Sep 1938	13.44 inches in Jun 1922	17.31 inches in Sep 1938	14.21 inches in Jun 1922
Minimum Monthly Precipitation	0.03 inches in Oct 1924	0.21 inches in Feb 1987	0.04 inches in Oct 1924	0.02 inches in Oct 1924	0.01 inches in Mar 1915	0.00 inches in Oct 1924
Figure No. displaying average monthly precipitation distribution	2.6-2	2.6-3	2.6-4	2.6-5	2.6-6	2.6-7
Periods of Record Evaluated	1893-2001 1917-1950 1951-2000	1984-2000	1912-2000 1917-1950 1951-2000	1907-2001 1919-1950 1951-2000	1906-2000 1917-1950 1951-2000	1906-2000 1917-1950 1951-2000

Note: Frozen precipitation is melted and reported as inches of water.

The average annual precipitation throughout the basin remains stable, averaging between 42-43 inches/year as shown in Figure 2.6-1. The average monthly precipitation was computed for each gage for various periods of record as summarized in the bottom row of Table 2.6-1. Generally, the three periods of record represent: full, 1917-1950 ("pre-1950"), and 1951-2000 ("Post-1950). As discussed later in this document, an analysis of USGS gages was conducted to determine any long-term changes in the magnitude and timing of runoff. Most of the USGS gages were operable starting around 1917 and continued through the 1990's. The pre-1950 period was selected under the assumption that water demands (withdrawals) were likely less during this period as compared to the post-1950 period. It was assumed that water development in the area generally increased after World War II. In addition, major changes in the basin occurred after 1950, namely the construction and completion of the Tully and Birch Hill Dams. Shown on each figure is the percent difference in precipitation for the post-1950 period relative to the pre-1950 period. In general, the post-1950 total average annual precipitation was 3-7% higher than the pre-1950 period. Generally, total average monthly precipitation was greater for the post-1950 period for all months except June and September. It should also be noted that in the early 1960's New England suffered a long-term drought, which influenced the precipitation statistics.

Using the Athol gage as a benchmark, there was little monthly variation in the long-term average precipitation ranging from a low of 2.85 inches (6.5% of the annual volume) in February to a high of 3.23 inches (9.4% of the annual volume) in July. The highest precipitation event occurred in September 1938 where 16-17 inches of precipitation fell. Because of this storm and floods in November 1927 and March 1936 the Corps built two flood control projects, one on the Millers River and one on the East Branch Tully River. The lowest precipitation month was consistently February.

Temperature data was obtained at the Corps' Birch Hill Dam for the period 1949-2000 as shown in Figure 2.6-8. The average annual temperature at Birch Hill Dam is 45 ºF, with monthly averages ranging from 68.4 ºF in July to 20.8 ºF in January.

2.7 History of the Millers River Basin

Information in this section was obtained from Millers River 1973 Water Quality Analysis.

The Millers River was first formed in the early tertiary period, 50 to 60 million years ago. The present state occurred over one million years ago. The river was originally much wider than now and has slightly altered its course over the years.

The Indians first settled in this area because of the river. Salmon and trout were abundant and the land along the river bank was fertile for planting corn. When the settlers arrived in the valley the Indians present were of the Nipmuck tribe. The first settlement in the area, Pequiog (or Athol as it was later renamed) was laid out and surveyed in the fall of 1732. In the fall of 1735 the first settlers arrived to attempt a permanent settlement.

The first communities were mainly centered on agriculture. The nineteenth century began the Industrial Revolution and the communities in the Millers River Basin began to shift their economic emphasis from agriculture to manufacturing. The river provided a convenient source of power; in fact most of the dams present in the river today were originally constructed for this purpose.

Due to the Industrial Revolution it was felt that there was a need to connect Boston with the West. Therefore, in 1825 a plan was developed to extend the Erie Canal to Boston. The proposed route would pass down the Millers River as well as the Charles, Nashua, and Deerfield

Rivers. The project was begun, but later abandoned due to difficulties and delays in completing the Hoosac Tunnel through the Berkshire Mountains. The Turners Falls canal was part of the original plan.

Although the canal system was never developed, the engineering and survey work that was involved played an important role in determining the route of the Vermont and Massachusetts Railroad. The Railroad began construction in 1847. When the Hoosac tunnel was finished, the link between Boston and the West was completed and the towns along the Millers River and the railroad prospered.

The increased growth in the basin also brought the beginning of pollution problems. The first references to this problem appear in the Orange Journal in the 1890's. Several articles refer to the degradation of water quality and the construction of sewer outfalls by upstream communities. However, examination by state health officials at that time showed the river to be clean. In 1922 the river was considered suitable for diversion to the proposed Quabbin Reservoir. In 1950, a report by the Massachusetts Department of Public Health evaluated the river as being "fairly good".

Up to this time only Winchendon and Gardner had constructed wastewater treatment facilities. Their facilities were completed in 1928 and 1921, respectively. This was insufficient and the river continued to deteriorate under increased domestic and industrial waste discharges, especially paper company effluents.

The Birch Hill and Tully Dams were constructed for flood control and went into operation in 1941 and 1948, respectively. The dams were constructed as a result of the 1927 and 1938 floods. During the most severe flood (1938), the flow at the Erving gage was 29,000 cfs, nearly 50 times the average annual flow.

Historically, the waters of the Millers River were full of salmon, trout and other fish. As noted above, settlement in the 17th century ushered in dams and mills that began to change the character and quality of the water. In the 1930's and 1940's the river was still one of the best-stocked trout streams in the state. However, by the 1950's pollution from industrial and domestic sources had ruined the Millers River for fishing and recreation. The river's color would vary from day to day, depending on what dyes the paper mills upstream were discharging.

After passage of the Clean Water Act (CWA), river water quality improved during the 1970's and 1980's. All municipalities and industries are now required to treat their discharges. However, a number of problems still remain in the watershed such as pollution from Polychlorinated Biphenyls (PCB's), chlorination, heavy metals, erosion, landfill leachate, stormwater runoff and acid rain. Fish consumption advisories have been issued on most of the river and on selected lakes.

3.0 Dam and Project Operations

The Millers River, like most watersheds in New England, has several dams that are used for various purposes including water supply, hydropower generation, industrial use, fire protection, flood storage, and recreation. Most of the dams were constructed many years ago to provide water and power for the region's industrial growth. Many of these dams have been abandoned and thus may not serve any function. Jerzy Pietrzak of the Massachusetts Office of Dam Safety (MODS), and Dale Guinn of New Hampshire Department of Environmental Services (NHDES) were contacted to obtain information on the dams within the Millers River Basin. Based on their databases, there are approximately 148 and 49 dams located in the Massachusetts and New Hampshire portions of the Millers River Basin, respectively (total estimate of 197 dams). General information on each dam (owner, structural height, year constructed, hazard classification, drainage area, etc) is provided in Appendix A of this document. The location of all dams in the Massachusetts portion of the Millers River Basin is shown in Figure 3.0-1 (data obtained from Massachusetts-GIS)[12].

There are ten dams on the Millers River mainstem, and another two on the North Branch Millers River. Most of the mainstem dams are equipped with hydropower turbines to produce electricity. In addition to these, there are numerous other dams along the Otter River, Tully River and the smaller tributaries of the Millers River. The US Army Corps of Engineers (Corps) operates two flood control projects in the Millers Basin, Birch Hill Dam on the Millers River and Tully Dam on the East Branch Tully River.

The Federal Energy Regulatory Commission (FERC) regulates hydroelectric projects throughout the United States. Typically FERC licenses are issued for large projects with a higher level of complexity and potential impact. In the northeast the majority of hydropower facilities underwent relicensing (the process of obtaining a new license) in the early 1990's. Typically, when a facility has undergone relicensing, new operational and environmental enhancements become part of the license. Operational changes typically include maintaining minimum flows, or changes to the operation of the hydroelectric facility to minimize impacts on aquatic and other natural resources. A FERC license is typically issued every 30-40 years for the continued operation of a hydropower facility. None of the hydropower projects in the Millers River Basin fall in this category. FERC issues an "exemption" for small hydroelectric projects, which meet certain criteria and generally have an installed generating capacity of 5 megawatts (MW) or less. When an exemption is granted the dam owner must accept the operational conditions (minimum flows, project operating conditions, etc) recommended by the Federal (United States Fish and Wildlife Service, USFWS) and state fish and wildlife agencies (Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement, MDFWELE). Four hydroelectric facilities on the Millers River mainstem are FERC exempt (New Home, Cresticon Lower/Upper, Tannery Pond and Hunts Pond). There is also one FERC non-jurisdictional facility, meaning there are no regulations that govern operations although the owner must report to the Massachusetts or New Hampshire Office of Dam Safety. The L.S. Starrett facility is in the non-jurisdictional category. In fact, most of the dams in the Millers River Basin fall under this category.

[12] It should be noted that an analysis of New Hampshire dam coverages was not part of the project scope.

It is also important to note that both Corps facilities (Birch Hill Tully Dams) are exempt from FERC licensing, thus there is no oversight with respect to how the facility is operated other than the Corps itself. As described later, the Corps and USFWS have recently been meeting to discuss the Birch Hill and Tully Projects.

3.1 Operation of Main Dams on the North Branch Millers River, Otter River, East Branch Tully River and the Millers River

It is important to understand the purpose, operation and function of the main dams in the Millers River Basin as they relate to flow regulation and how aquatic resources below each project might be affected. For example, the Birch Hill and Tully Dams were constructed to control flooding along the Millers and Connecticut Rivers. Flood control operations affect the timing and magnitude of spring flows that would otherwise naturally occur below these projects. Other dams in the basin serve various purposes including recreation, water supply, and hydropower generation. Again, the operation of these dams may also affect the timing and magnitude of river flow. Many of the projects are required to operate as run-of-river facilities, where inflow instantaneously equals outflow. United States Geological Survey (USGS) gage flow data, collected downstream of several dams were examined to determine if facilities were operating according to their FERC exemption requirements.

It is beyond the scope of this study to evaluate the operation and purpose of all 197 dams in the Millers River Basin. Instead emphasis was placed on larger facilities (facilities considered to have the ability to significantly regulate the river) as well as those considered to be high hazard[13] dams. Table 3.1-1 (end of this section) is a summary of the major dams along with information on the owner, hydropower generation capacity (if applicable), minimum flow requirements (if applicable), primary purpose of the facility, hazard classification, and year constructed. The location of Massachusetts's dams is also shown in Figure 3.1-1.

The following section describes the operation of each dam listed in Table 3.1-1. For the FERC exempt projects, the USFWS was contacted to obtain the license conditions that govern the operation of these facilities. For the Corps facilities, the project manager or park ranger was contacted to obtain similar information. In addition, the Corps maintains websites for both Tully and Birch Dams, which were reviewed to gain further insight on the operation of each project. For the remaining projects, telephone interviews were held with the dam owners or operators. It should be noted that most of the facilities in the basin (except the FERC exempt projects and Corps facilities) do not have operating requirements, such as minimum flows, other than dam safety issues. Thus, owners were asked how the facilities were operated. In most cases, these smaller sites were operated as run-of-river facilities, except during periods when flashboards were removed in the fall and then replaced after the spring runoff.

[13] High Hazard- If a dam were to fail, lives would be lost and extensive property damage could result.

3.1.1 Major Dams-North Branch Millers River

3.1.1.1 Lake Monomonac Dam(s)- Main Dam, Emergency Spillway and Red Dam

The town of Winchendon operates the Lake Monomonac Dam, which is located on the North Branch Millers River (see Figure 3.1.1.1-1). Based on discussions with Mike Murphy, Superintendent of Public Works, there are three dams currently impounding Lake Monomonac. The main dam currently has a siphon through it- the dam will eventually be breached and replaced with a box culvert. Red Dam, which is located downstream of the main dam was constructed to hold water against the main dam (due presumably to dam safety issues). On the west side of the lake there is an emergency spillway with 2 ft x 6 ft flashboards. The flashboards are removed in the fall and replaced just after the spring runoff. There are no low-level outlets to release a minimum flow. The town strives to maintain a stable lake elevation throughout the summer period. The lake is used primarily for recreation purposes.

3.1.2 Major Dams-Upper Watershed of the Millers River

3.1.2.1 Upper Naukeag Pond Dam

Upper Naukeag Pond Dam is owned and operated by the town of Ashburnham (see Figure 3.1.1.1-1). It is located upstream of Lower Naukeag Pond Dam, which eventually drains into the Millers River. Based on discussions with Bill Brennan, Superintendent of Public Works for the town of Ashburnham, the impoundment is used for water supply purposes, providing drinking water to the towns of Winchendon and Ashburnham. No motorboats, sailboats or canoes are allowed on the lake. The lake level is typically maintained stable year-round (run-of-river), but occasionally the lake may be drawn down 6 inches in the winter.

3.1.2.2 Lower Naukeag Pond Dam

Lower Naukeag Pond Dam is also owned and operated by the town of Ashburnham (see Figure 3.1.1.1-1). According to Mr. Brennan, the lake is maintained stable during the summer and then lowered approximately five feet in the late fall for purposes of weed control. After about three frosts to control weeds, the lake is refilled (flashboards are replaced) in late fall/early winter during which flows below the dam become reduced during the refill period. The lake depth is approximately 10-12 feet.

3.1.3 Major Dams- Otter River

3.1.3.1 Seaman Paper Co. Otter River Dam

The Otter River Dam is owned and operated by Seaman Paper Company (see Figure 3.1.3.1-1). George Jones of Seaman Paper indicated that the purpose of the dam is to divert water for processing needs for the paper mill. There is a sluice gate at the dam that is used to control water levels. A minimum impoundment level is required to divert water to the mill. Processing water is used, treated and then discharged downstream (an NPDES permit exists).

3.1.4 Major Dams- East Branch Tully River

3.1.4.1 Tully Dam Flood Control Facility

Tully Lake is located on the East Branch Tully River in Royalston, Massachusetts, and is part of a network of flood control dams operated by the Corps on tributaries of the Connecticut River (see Figure 3.1.4.1-1 for picture). Its function is to reduce flood stages in Athol, Orange and other communities along the Millers River, and in conjunction with other Corps dams reduce flood stages along the Connecticut River.

The Reservoir Regulation Team (RRT), located at the Corps' New England District Headquarters in Concord, MA, is the "nerve center" for all Corps-operated dams in New England. Using radio and satellite communications, the RRT constantly monitors river levels and weather conditions and directs the operation of the dams during high flows. Park rangers regulate the Tully Lake discharges by raising or lowering two 3.5 ft x 6 ft gates located in the gatehouse at the dam. During high flow conditions, the gates are lowered to impound water. After a high runoff event and as flows downstream recede, the gates are opened further to release water.

Based on discussions with Jeff Mangum, Park Manager, Tully Lake is maintained at different elevations throughout the year. In the summer the lake level is near stable at the recreation pool elevation of 641 ft (NGVD). In the fall, the lake is lowered and then held near stable again in the winter at 636 ft, NGVD. The current (as of September 2002) minimum flow at the project is 10 cfs (0.20 cfsm), which is equivalent to opening one of the gates 0.10 feet- the lowest possible setting.

Flow conditions permitting, Tully Lake is also operated to maintain flows for the River Rat and Farley Flats races that occur during the first two weekends in April. The drainage area near Farley Flats is 372 mi^2. The target flow for both races is 1,900 cfs in Athol. To date approximately 1,500 cfs is released from the Birch Hill Dam and another 400 cfs from Tully Dam.

The Corps and USFWS are currently having discussions relative to how the Corps operates both the Tully and Birch Hill facilities. Some of the concerns expressed by the USFWS include:

- the magnitude of flow releases provided from both Corps facilities during the Farley Flats and River Rat races. The USFWS would prefer to limit the special releases to not exceed 6 cfs per square mile of drainage (cfsm) or 1,050 cfs from Birch Hill and 300 cfs from Tully Lake for a combined total of 1,350 cfs. Birch Hill and Tully Lake comprise 225.5 mi^2 of the 372 mi^2 (this is the drainage area at Farley Flats) or 61% of the drainage. The USFWS suggests that natural runoff from the remaining 146.5 mi^2 coupled with 1,350 cfs of regulated releases should be sufficient for maintaining 1,900 cfs in Athol.
- the rate of flow change below each flood control facility is a concern to the USFWS- in other words the rate at which discharges increase and decrease at the onset of the spring runoff, after the spring runoff, and during non-flood periods. The USFWS recommended that during all non-flood period flow increases and decreases, flows be adjusted at a

maximum rate of 0.5 cfsm per hour when inflows are less than 4.0 cfsm and a maximum discharge rate of 1.0 cfsm when inflows exceed 4.0 cfsm.
- maintaining a minimum flow below each project during the spring.

To further evaluate the operation of Tully Lake, the Corps provided hourly discharge and elevation data for the last few years. These data, along with other gages in the basin, were evaluated later in this document to understand how operations affect the timing, magnitude, rate of change and frequency of flow in the East Branch Tully River. The Corps also monitors a gage on the Millers River in Athol, which they use to regulate discharges from the Birch Hill and Tully Dam facilities. The accuracy of the Athol gage has been questioned as described later in this document.

3.1.5 Major Dams-Millers Rivers

3.1.5.1 Sunset Lake Dam

The Far Hills Association privately owns Sunset Lake and dam (see Figure 3.1.1.1-1). Based on conversations with Paul LeBlanc, the Association Director, the spillway is equipped with 2 ft x 6 ft flashboards as well as a low-level gate. The flashboards can be maintained year-round since the low-level outlet serves to lower the lake in the fall. In early April, the gate is closed further to allow the lake to refill to full pond. During the summer the lake is maintained stable for recreation purposes.

3.1.5.2 Whitney Pond Dam

The town of Winchendon owns and operates Whitney Pond Dam, which forms the headwaters of the Millers River. Whitney Pond is a defunct hydropower project, which has been inoperable for over 60 years. Mike Murphy has indicated that the 130-foot long dam has 2 ft x 8 ft flashboards, which are maintained year round. The project is operated as a run-of-river facility. See Figure 3.1.5.2-1 for a picture of Whitney Dam and the surrounding topography.

3.1.5.3 Hunts Pond Dam

Hunts Pond Dam is the middle of three dams in series (Whitney Dam is upstream and Tannery Dam is downstream) on the Millers River in Winchendon, MA as shown in Figure 3.1.5.3-1. The O'Connell Energy Group owns this FERC-exempt project. It includes two turbines with a total capacity of 120 kW (30 and 90 kW units). According to the USFWS the total turbine capacity of the project is 172 cfs (Melissa Grader, USFWS, personal communication). The drainage area at the facility is 54 mi^2. The FERC exemption for this project was issued by the USFWS on August 24, 1984 requiring the following:

- The facility must be operated in a true run-of-river manner, whereby outflow equals inflow instantaneously.
- The tailrace discharge is located at the base of the dam, thus there is no bypassed reach channel. The exemption requires an instantaneous minimum release of 25 cfs (historical

median August Flow) or inflow to the project; whichever is less, to conserve aquatic resources.
- The owner is required to provide fish passage facilities when prescribed by the USFWS and/or the MDFWELE.

3.1.5.4 Tannery Pond Dam

Tannery Pond Dam is located downstream from Hunts Pond Dam in Winchendon, MA as shown in Figure 3.1.5.4 -1. This FERC exempt facility is currently operated by Swift River Hydro Operations and has a drainage area of approximately 54 mi^2. The project contains a river reach bypassed by the hydropower project. Essentially, this means that water is conveyed (via a canal or penstock) from the impoundment to a powerhouse located downstream of the dam, hence a portion of the natural stream channel is "bypassed" by the hydropower facility. The exemption for this project was issued by the USFWS on April 23, 1986 requiring the following:

- The facility must be operated in a true run-of-river manner, whereby outflow equals inflow instantaneously.
- An instantaneous minimum flow of 26 cfs (historical median August flow) or inflow to the project, whichever is less, is required to protect downstream aquatic habitat.
- An instantaneous minimum flow of 6 cfs or inflow to the project, whichever is less, is required to conserve aquatic habitat in the bypassed reach. The 6 cfs flow is based on the 7Q10[14].
- The owner is required to provide fish passage facilities when prescribed by the USFWS and/or the MDFWELE.

3.1.5.5 Birch Hill Flood Control Facility

Birch Hill Dam is located on the Millers River in South Royalston, Massachusetts, and is a part of a network of flood control dams on tributaries of the Connecticut River (see Figure 3.1.5.5-1). Birch Hill Dam was one of the first dams the Corps built in New England to prevent floods like those that devastated Athol and Orange in 1936 and 1938. This dry-bed[15] reservoir is operated for flood control purposes by storing high flows for later release, as flow conditions warrant. Corps personnel, in conjunction with the RRT, regulate the amount of water released downstream by raising or lowering the four 6 ft x 12 ft gates located in the dam gatehouse.

There is a USGS gage in South Royalston, MA, located downstream of Birch Hill Dam. There is approximately 14 mi^2 of drainage area between the Birch Hill Dam release (175 mi^2) and the South Royalston gage (189 mi^2).

[14] "7Q10" means the lowest average flow rate for a period of 7 consecutive days with an expected recurrence interval of once in every 10 years.

[15] As a dry-bed reservoir, the dam is designed to pass normal flows from the Millers River without impounding water. Dry-bed reservoirs typically function as reservoirs when the amount of water entering the project (inflow) exceeds the project's capacity to discharge it through the outlet works.

The Corps operates a streamflow gage in Athol, which is located below both the Tully Lake and Birch Hill flood control facilities. The Corps uses this gage as a barometer of flow conditions in the Millers River and makes discharge adjustments at the flood control projects depending on river flow. The Corps noted that a warning occurs when river flow reaches 2,670 cfs at the Athol gage, and is considered in flood stage at 3,155 cfs.

Based on discussions with James Bacon, Project Manager, there is a minimum flow of 25 cfs (equivalent to 0.14 cfsm) at Birch Hill Dam, except during periods of extremely low flow, when discharges may be less than 25 cfs. In addition to flood control operations, special releases are provided for the first two weekends in April for the River Rat Race and Farley Flats race. There is little to no manipulation of Birch Hill water levels during the summer. These special releases are made only when sufficient flow is available.

Lake Dennison is a natural lake located upstream of Birch Hill Dam. During periods of storing water at Birch Hill Dam, some of the campgrounds surrounding the lake can become inundated. Lake Dennison is heavily used in the summer for recreational uses (i.e. camping, fishing, swimming, and boating).

As described earlier, the Corps and USFWS are discussing various issues regarding the operation of Birch Hill and Tully Dams.

3.1.5.6 Cresticon Upper and Lower Dams

Cresticon Upper and Lower dams are two separate facilities that are owned by L.P. Athol Corporation and located in Athol, MA as shown in Figure 3.1.5.6-1. Phillip Purple, the station operator, indicated that Cresticon Upper has a rated capacity of 250 kW, but in reality the peak capacity is approximately 170 kW. The total turbine capacity of Cresticon Upper is 207 cfs. Cresticon Lower has a rated capacity of 250 kW, but in reality the peak capacity is roughly 230 kW. The turbine capacity of Cresticon Lower is 400 cfs. The drainage area at the project is approximately 200 mi^2. A relatively short free-flowing riverine reach separates Cresticon Upper and Lower. Both facilities have bypassed river reaches. The exemption for this project was issued by the USFWS on March 7, 1986 and includes the following:

- Both facilities are to be operated in a true run-of-river manner, whereby outflow equals inflow instantaneously.
- An instantaneous minimum flow of 95 cfs (historical median August flow) or inflow to the project, whichever is less, is required to protect downstream aquatic habitat below both facilities.
- An instantaneous minimum flow of 25 cfs, or inflow to the project, whichever is less, is required to conserve aquatic habitat in the bypass reaches.
- The owner is required to provide fish passage facilities when prescribed by the USFWS and/or the MDFWELE.

3.1.5.7 Starrett (Crescent Street Dam)

The Crescent Street Dam and hydropower facility, which is owned by L.S. Starrett, is FERC non-jurisdictional. The facility has two turbines with nameplate capacities of 112 kW and 250 kW (L.S. Starrett indicated that the turbines produce less than the nameplate capacity). The facility is operated as run-of-river. A hydraulically operated float is used to adjust their crest gate to maintain a stable pond. L.S. Starrett indicated that they observed pulsing inflows from upstream hydropower projects. Shown in Figure 3.1.5.6-1 is photograph of the dam.

3.1.5.8 New Home Dam

New Home Dam is located near Orange, MA as shown in Figure 3.1.5.8-1. The facility is owned by the O'Connell Energy Group and has three units with a total capacity of 425 kW (160 kW, 130 kW, and 135 kW). According to USFWS records, the total turbine capacity of project is 1,112 cfs. The facility contains a bypass reach. The exemption for this project was issued by the USFWS on March 7, 1986 and includes the following:

- The facility is to be operated in a true run-of-river manner, whereby outflow equals inflow instantaneously.
- An instantaneous minimum flow of 152 cfs (historical median August flow) or inflow to the project, whichever is less, is required to protect downstream aquatic habitat.
- An instantaneous minimum flow of 10 cfs or inflow to the project, whichever is less, is required to conserve aquatic habitat in the bypassed reach.
- The owner is required to provide fish passage facilities when prescribed by the USFWS and or the MDFWELE.

In 2001 and 2002, there was considerable correspondence between O'Connell Energy Group, FERC and Trout Unlimited (TU) regarding the operation of New Home Dam. Based on analysis shown later in this study, it appears that the New Home Dam was not operating in compliance with the FERC exemption as pulsing flows were observed during the summers of 2000 and 2001 below the project (as measured at the Erving USGS gage). All correspondence between FERC, O'Connell Energy Group and TU is shown in Appendix B.

The minimum flow conditions for the FERC exempt projects are summarized in Table 3.1.5.8-1

Table 3.1.5.8-1: Summary of Minimum Flow Requirement at the FERC Exempt Projects

Name	Drainage Area (mi^2)	Minimum Flow Requirement (cfs)	Method used to determine minimum flow requirement
Hunts Pond Dam	54 mi^2	25 cfs	historic median August flow
Tannery Dam	54 mi^2	26 cfs	historic median August flow
Tannery Dam Bypass	54 mi^2	6 cfs	7Q10
Cresticon Dam	200 mi^2	95 cfs	historic median August flow
Cresticon Bypass	200 mi^2	25 cfs	approximate 7Q10
New Home Dam	375 mi^2	152 cfs	historical median August flow
New Home Dam Bypass	375 mi^2	10 cfs	visual interpretation

Table 3.1-1: Summary Data on Major Dams Located in the Millers River Basin[16]

Dam Name	Owner	Drainage Area (mi²)	Hydropower Generation Capacity (kW), if applicable	Hydropower Total Turbine Capacity (cfs), if applicable	Minimum Flow below Project (cfs), if applicable	Is there a bypass reach? If so, what is the min flow, cfs	How is project operated (run-of-river, peaking hydro, storage, etc)	Primary purpose of dam and impoundment (recreation, water supply, flood control, hydropower, industrial use, etc)	Structural Height of Dam (feet)	Hazard Classification	Reservoir Storage Area (acre-ft)	Year Built
North Branch, Millers River												
Lake Monomonac	Town of Winchendon	19.06 mi²	-	-	-	-	run-of-river	Recreation	19 ft	High	9080 ac-ft	1923
Red Dam	Town of Winchendon	18.73 mi²	-	-	-	-	run-of-river	Recreation	15 ft	High	15 ac-ft	?
Upper Millers River												
Upper Naukeag Pond Dam	Town of Ashburnham	2 mi²	-	-	-	-	run-of-river	Water Supply	8 ft	High	3,100 ac-ft	1875
Lower Naukeag Pond Dam	Town of Ashburnham	12 mi²	-	-	-	-	run-of-river	Recreation	14 ft	High	2,800 ac-ft	1900
Sunset Lake Dam	Far Hill Association	7.5 mi²	-	-	-	-	run-of-river	Recreation	12 ft	Low	1,785 ac-ft	1900
Otter River												
Otter River Dam- Seaman Paper Co.	Seaman Paper Company, Inc	41 mi²	-	-	-	-	run-of-river	Industrial Use	10 ft	Low	106 ac-ft	1900
East Branch, Tully River												
Tully Dam	Army Corps of Engineers	50 mi²	-	-	10 cfs	-	run-of-river	Flood Control, Recreation	62 ft	High	35,800 ac-ft Flood Storage capacity= 49,900 ac-ft	1949
Millers River												
Whitney Pond Dam	Town of Winchendon	53 mi²	-	-	-	-	run-of-river	Recreation	25 ft	High	2,186 ac-ft	1880
Hunts Pond Dam	O'Connell Energy Group	54 mi²	320 kW		25 cfs or-inflow	-	instantaneous run-of-river	Hydropower, Recreation	16 ft	Significant	120 ac-ft	1936
Tannery Pond Dam	Swift River Hydro Operations	54 mi²			26 cfs or-inflow	Yes, 6 cfs	instantaneous run-of-river	Hydropower	17 ft	Significant	51 ac-ft	1875
Birch Hill Dam	Army Corps of Engineers	175 mi²	-	-	25 cfs or-inflow	-	flood control, store spring runoff, drawdown in fall	Flood Control	56 ft	High	76,000 ac-ft Flood storage capacity= 49,900 ac-ft	1941
L.P. Athol Dams (2) Cresticon Upper Cresticon Lower	L.P. Athol Corporation	200 mi²	 250 kW (actual-170 kW) 250 kW (actual 230 kW)	 207 cfs 400 cfs	95 cfs or-inflow	Yes, 25 cfs or-inflow	Instantaneous run-of-river	Hydropower	19 ft	High	260 ac-ft	1923
L.S. Starrett Dam (Crescent Street Dam)	L.S. Starrett Co.	201 mi²	360 kW			-	run-of-river	Hydropower, Water Supply	28 ft	High	87 ac-ft	1900
New Home Dam	O'Connell Energy Group	? mi²	427 kW		152 cfs or-inflow	Yes, 10 cfs or-inflow	run-of-river	Hydropower	10 ft	Low	452 ac-ft	1942

Source: Massachusetts's Office of Dam Safety and telephone interviews with station operators or owners.

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[16] There are numerous dams located in the Millers River Basin. The list above are those dams located on the North Branch Millers River, the Millers River, and the largest two tributaries to the Millers River, Tully River and Otter River. Thus, Table 3.1-1 is not a complete listing of all dams in the watershed. A complete list of dams can be found in Appendix A.

4.0 Millers River Basin- Summary of Water Management Act Withdrawals

The Massachusetts Water Management Act became effective in March 1986. The purpose of the Act is to ensure adequate volume and quantity of water for all citizens of the Commonwealth, both present and future. Implementation of the Water Management Act has taken place in two phases: registration and permitting of water withdrawals. Water withdrawals in Massachusetts that average over 100,000 gallons per day (GPD) need to be registered or permitted. Withdrawals that exceed their volume by 100,000 GPD, proposed increases in the withdrawal amount and new sources, need to be permitted. These conditions apply to any entity withdrawing water such as public water suppliers and industrial, commercial, golf courses and agricultural users. Those who obtain (purchase or transfer) their water from another water system do not require a WMA permit.

The deadline for filing a WMA registration statement was January 4, 1988. The purpose of the registration was to grant continued water rights to existing water withdrawals and to provide the Massachusetts Department of Environmental Protection (MDEP) with information needed to begin the process of comprehensive water management. The permitting phase of the program went into effect over several years. The deadline for submitting permit applications for the first round of permitting in the Millers River Basin was February 28, 1993.

There are several water withdrawal locations in the Millers River Basin, although the majority of users withdraw less than 100,000 GPD. Shown in Figure 4.0-1 is a map depicting the location of most water supply water withdrawals (this does not include all industrial users, as Mass GIS does not have this information readily available). The WMA registered and/or permitted sources exceeding 100,000 GPD are shown on Figure 4.0-2 and listed in Table 4.0-1 including industrial users.

Table 4.0-1: WMA Registered and Permitted Water Withdrawals in the Millers River Basin (>100,000 GPD or 0.1 MGD)

Name	Registration No.	Registered No. of Withdrawal Points (SW- surface water, GW- groundwater	2000 Average Daily Rate (MGD)	Permitted Average Daily Withdrawal in 2000 (MGD)
Public Water Suppliers				
Ashburnham Water Department	2011000	1 SW	0.21	0.18
Athol Department of Public Works- Water Division	2015000	3 GW	0.85	1.04
Gardner Department of Public Works- Water Division	2103000	1 GW, 1 SW	2.02	1.69
Orange Water Department	1223000	3 GW	0.66	0.93
Templeton Water Department	2294000	4 GW	0.48	0.84
Winchendon Water Department	2343000	1 SW	1.06	0.67

Name	Registration No.	Registered No. of Withdrawal Points (SW- surface water, GW- groundwater	2000 Average Daily Rate (MGD)	Permitted Average Daily Withdrawal in 2000 (MGD)
Industrial Users				
American Tissue Mills of Mass., Inc.	10709101	2 SW	out of operation since 9/1995	2.02
Erving Paper Mills	10709102	1 SW, 2 GW	2.02	2.66
International Paper Company-Strathmore Millers Falls Facility	10719201	1 SW, 1 GW	0.36 (1999 data) out of operation since 8/2000	0.75
Seaman Paper Co. of MA, Inc	2-07-294.02	1 SW, 1 GW	1.08 (1999 data)	1.19

Gomez and Sullivan visited the MDEP Springfield and Worcester offices to obtain copies of the reports listed below, which were needed to evaluate water withdrawals in the Millers River Basin:

- The WMA Registration Statement for each water withdrawal,
- The WMA permit [Massachusetts General Law (MGL) c 21G],
- Public Water Supply Annual Statistical Reports (PWSASR) for each water supplier from 1993 to 2000. It should be noted that in some cases not all of the reports were available from the MDEP.
- WMA Annual Reports for industrial, agricultural and golf course withdrawals from 1993 to 2000. Not all of the reports were available from the MDEP. It should also be noted that the public water supply reports and industrial reports contain the same basic information, although the public water reports contain information on peak water usage.

Each WMA user in the Millers River Basin was examined in this report. All of the WMA users listed below were telephoned to gain a better understanding of their system. The annual reports provide only so much information, and telephone calls to the water users helped refine the evaluation. In addition, to ensure that the description of each water user was accurate, the sections below were faxed to each supplier for review and comment.

Each WMA user was evaluated to understand the magnitude and timing of withdrawals, as well as the timing of peak withdrawals (applies only to public water suppliers). In addition, other components of each WMA system was evaluated including: population served, average daily consumption (gallons per capita per day- gpcd), peak daily consumption, main water users (residential, commercial, etc), unaccounted for water, and any information on water conservation plans.

A few notes are worth mentioning when reviewing the average daily consumption (gpcd) and unaccounted for water (UAW) results discussed below. It is important to note that in some of the smaller towns the population served is overestimated, which results in a low consumption use in gpcd. Some residents in a town utilize private wells. Also, the water suppliers know the number of connections they serve, but not necessarily the number of people. Because some water suppliers report a higher population served than in reality, the average gallons per capita day is below 80 gpcd. The MDEP uses 70-80 gpcd as a flag to evaluate water usage in more detail. When reviewing the Public Water Supply Annual Statistical Reports, the MDEP determines if the reported gpcd is excessively high (greater than 80 gpcd), and then probes further into the cause(s) such as leak detection, summer water use and other water conservation issues. In summary, although the gpcd is less than 80, it may not necessarily translate into aggressive water conservation measures. In the analysis below, there are instances where the computed gpcd is well below 80 (such as 26 gpcd). Values this low are unrealistic and are most likely a function of the population reported.

Similarly, if unaccounted-for-water (UAW) exceeds 10-15%, it is a flag to the MDEP to investigate further the breakdown of lost water. Often water providers do not differentiate water lost to hydrant flushing or fire fighting, which, according to MDEP is not technically UAW. Systems that are below 10-15% are still required to conduct leak detection surveys and pursue water conservation strategies.

Another key component of our research was to determine if a given water user had storage capacity within their system such as reservoirs or sizeable storage tanks. The purpose for collecting this information was to determine if storage capacity could be used to supplement demand during low flow periods such as in the summer, when aquatic resources are most apt to be affected by reductions in the magnitude of natural flow. Summer water withdrawals could presumably be curtailed if sufficient storage capacity were available to supplement water supply needs, which would result in less stress on aquatic resources. Overall, there is minimal water supply storage capacity in the Millers River Basin.

Another component of the analysis was to identify the withdrawal location as well as the return location, typically a wastewater treatment plant (WWTP). In some instances, it was unclear if all the water provided by Water Supply Company X was returned to Wastewater Treatment Plant Y. It should be noted that not all water withdrawn from a given source was returned to a WWTP, as losses of water could include:

- discharges to septic systems and not WWTP's,
- water supply systems have unaccounted-for-leakage, thus the amount of water withdrawn is not equivalent to the actual amount delivered to customers as a result of leaks, fire use, etc.
- water lost to evapotranspiration or evaporation resulting from car washes, agricultural, lawn irrigation, or filling swimming pools.

Although affected riverine reaches were identified, the scope of this study did not include any field verification to evaluate potential impacts. Several water supply sources were from groundwater wells and in some cases it was difficult to determine whether the zone of withdrawal was hydraulically connected to a given river or brook. In general, if the withdrawal point was in relatively close proximity to a river, it was assumed to be hydraulically connected to the river. It should be noted that most water suppliers withdraw water continuously; withdrawals are not pulsed throughout the day as may be experienced by other human activities such as WWTP discharges or hydropower project operations. Thus, the true effect of water withdrawals is a reduction in the magnitude of flow, and perhaps the seasonal timing of withdrawal (more water is typically used in the summer).

Shown in Appendix C are all of the water withdrawal data (for each water supplier) used to generate the graphs in the following sections.

4.1 Ashburnham Water Department (Millers River Basin)

Public Water Supply No.: 2011000
Registration No.: 2-07-011.01

The Ashburnham Water Department (AWD) withdraws water from the spring-fed Upper Naukeag Lake. When AWD registered for water withdrawals in 1991, their average volume per day was 0.18 MGD (65.70 MGY).

Winchendon Water Department (WWD) also uses Upper Naukeag Lake for public water supply. A pipeline runs through the town of Ashburnham that carries water to Winchendon. Some of this water is diverted to Ashburnham customers before it reaches the town of Winchendon. Winchendon bills Ashburnham for the use of this water.

It should be noted that in October 2001, WWD and AWD installed flow recorders to more accurately report water withdrawal volumes. According to Mike Murphy (Winchendon Department of Public Works Superintendent), the flow recorders are showing that WWD over reported their withdrawal volume by approximately 19%. Likewise, Mr. Murphy indicated that AWD under reported their withdrawal volume by approximately 27%. The analysis presented in this section and in the WWD section is based on pre-October 2001 conditions.

4.1.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.1.1-1 is AWD's total withdrawal volume (MGY), average daily withdrawal (MGD), and peak withdrawal (MGD) for the period 1993-2000. The annual withdrawal volume during this period has been relatively consistent, ranging from 74 MGY to 102 MGY. In each of these years the average daily demand (82.7 MGY) has exceeded the registered amount of 0.18 MGD or 65.70 MGY. However, the regulations allow water suppliers to withdraw an additional 100,000 GPD (36.5 MGY) above their WMA withdrawal and remain in compliance. AWD's registration is 65.7 MGY (an additional 36.5 MGY equates to 102.2 MGY, thus AWD is just in compliance for 1997).

Over these eight years, the peak demand has occurred mainly in the summer months with one exception, as follows: January (1), June (2), July (2), August (1) and September (2). The average difference between the average daily demand and peak demand over the last eight years is approximately 0.18 MGD. The average ratio of peak demand relative to average annual demand is 1.78.

The evaluation of seasonal demand was conducted to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.1.1-2 is a bar graph depicting, by month, the water withdrawals from Upper Naukeag Lake. The monthly water usage varies ranging from a low of 5.9 MGM in February to 8.3 MGM in July. As anticipated, water demands were highest in the summer and lowest in the winter.

4.1.2 Storage Capacity

AWD maintains two above ground storage tanks; each holds 0.5 MG of water to pressurize the system. The total storage capacity of Upper Naukeag Lake is reported to be 1 MG. The total storage capacity of the system (2 MG) relative to the average annual demand (83.4 MG) is minor.

4.1.3 Customers/Unaccounted Water

The Public Water Supply Annual Statistical Reports (PWSASR's) contain information on the service type (residential, industrial, commercial, etc) that utilize the water supply. Between 1993 and 2000 the service type or categories have changed. For example in 1993 there were only a handful of categories such as residential, commercial, etc. In 1996, and again in 2000, the categories were further refined. On the 2000 PWSASR's, residential usage was broken down into residential area, mobile home park, other residential area, semi-residential, etc. Because it is difficult to accurately categorize the data for all years, the most recent 2000 data was used.

Based on the 2000 PWSASR, 48% of the water supply is for residential use followed by schools (15%). Per discussions with William Brennan, Jr., Superintendent of AWD, some of the water taken from Upper Naukeag Lake is conveyed via water lines to customers in the Nashua River Basin (part of Ashburnham is in the Nashua River Basin), although the percentage conveyed is unknown. Based on visual observation, it appears that a large percentage of the Ashburnham town center is located outside the Millers River Basin.

Water providers also report unaccounted for water (leaks, fire hydrant flushing, pipeline flushing, etc). During the period 1993-2000, unaccounted for water constituted an average of 13% of the total water supply. This value exceeds the state's water conservation goal of less than 10 %. The MDEP requires that water suppliers having 15% or greater unaccounted for water indicate the possible reasons. In 1997, unaccounted for water represented over 31% of the total water supply. According to Mr. Brennan, the sharp increase in unaccounted for water in 1997 was likely due to fires and leaks.

4.1.4 Population Served

According to the PWSASR, the population served was 5,000 in the winter and 6,000 in the summer from 1993-1998. These population estimates closely approximate the census numbers for town of Ashburnham. In 1999 and 2000, the population served was reported as 2,675 for both the summer and winter. The 2,675-population figure was determined based on the total number of residential connections multiplied by the average number of people per household (Personal Communication, William Brennan, Jr.). For the period 1993-1998, residential gallons per capita day (gpcd) ranged from 19-23. With the population reported as 2,675 in 1999 and 2000, residential water use was estimated at 49 and 39 gpcd, respectively. There is an obvious shift in the gpcd due to how the population served was reported. Shown in Figure 4.1.4-1 is the population served and the residential gpcd for the period 1993-2000. The average daily usage for the period 1993-2000 is 26 gpcd, which is well below the state's water conservation goal of 80 gpcd for residential use, but is also unrealistically low.

It should be noted that the town of Ashburnham does not have a wastewater treatment facility. According to Mr. Brennan, the entire town's wastewater is transported approximately 6.5 miles to the City of Gardner for treatment, before discharging to the Otter River.

4.1.5 Water Conservation Measures

AWD currently does not have a formal water conservation policy in place, however there are bylaws that they follow in order to impose water conservation requirements on customers.

4.1.6 Area Affected by Water Withdrawals

The drainage area at the outlet of Upper Naukeag Lake is 2 mi^2. Water withdrawn from the spring-fed Upper Naukeag Lake reduces the magnitude of flow below Upper Naukeag Lake Dam, which eventually flows into Lower Naukeag Lake and then into the Millers River. During the highest demand month, July, the total monthly withdraw is 8.3 MG (or an average of 0.41 cfs/day). Converting this average daily withdrawal rate to a flow per square mile at the lake outlet equates to 0.21 cfsm (0.41 cfs/2 mi^2). This represents a large portion of the flow volume, and coupled with the Winchendon Water Department withdrawal will likely significantly reduce flow below the dam outlet in the summer. According to Mr. Brennan Upper Naukeag is operated near run-of-river, thus the lake level is not drawn down to supplement water supply demands.

As noted above, the Upper Naukeag Lake serves the water users in Ashburnham; however, wastewater is collected at the Gardner WWTP and then returned to the Otter River. Thus, there is a net reduction in flow in the Millers River and a net gain in flow in the Otter River.

In addition, an unknown percentage of the Upper Naukeag water supply is transferred to the water users in the Nashua River Basin. This results in a net loss of water from the Millers River Basin.

4.2 Winchendon Water Department (Millers River Basin)

Public Water Supply No.:	2343000
Registration No.:	2-07-343.01

The Winchendon Water Department (WWD) is also registered to withdraw water from Upper Naukeag Lake located in Ashburnham, MA. The registered withdrawal per day is 0.67 MGD (245.06 MGY). Per discussions with Michael Murphy, Winchendon Department of Public Works Superintendent, WWD applied for a new permit in 2001 to increase their water withdrawal amounts from Upper Naukeag Lake to 1.1 MGD. A safe yield analysis was conducted, which resulted in an estimated 1 MGD from Upper Naukeag Lake.

Based on the period 1993-2000, WWD sold water to the Ashburnham Water Department. Over this period, the average annual sales were 26.5 MGY or 0.07 MGD. Note that Ashburnham is also drawing water from Upper Naukeag Lake for public water supply.

As noted above, in October 2001, WWD and AWD installed flow recorders to more accurately report water withdrawal volumes. Prior to October 2001, WWD over reported their withdrawal volume by approximately 19%. The analysis presented in this section is based on pre-October 2001 conditions.

4.2.1 Annual and Monthly Withdrawal Volumes

Figure 4.2.1-1 shows the annual total withdrawal volume (MGY), average daily withdrawal (MGD), and peak withdrawal (MGD) for the period 1993-2000. The annual withdrawal volume in 1993 was relatively low at 236.4 MGY. Since then, the annual demand has been relatively consistent, ranging from 376.5 MGY to 434 MGY. These annual volumes well exceed the registered withdrawal of 245.06 MGY (keep in mind that withdrawals were over reported by approximately 19%- although even with adjustment withdrawals are still above the registered volume).

Over these eight years, the peak demand has consistently occurred in the summer months as follows: June (1), July (5) and August (2). The average difference between the average daily demand and peak demand over the last eight years is approximately 0.60 MGD. The ratio of peak demand relative to average annual demand is 1.57.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.2.1-2 is a bar graph depicting, by month, the water withdrawals from Upper Naukeag Lake. As anticipated, water demands are highest in the summer (July- 37.1 MG/month), and lowest in the winter (February- 29.1 MG/month).

4.2.2 Storage Capacity

Per conversation with Mr. Murphy, WWD has four storage tanks in the system with a total capacity of 2.566 MG, which are used to pressurize the system. The total storage capacity relative to the average annual demand (379 MG) is minor.

4.2.3 Customers/Unaccounted Water

New equipment installed at the WWD allowed the volume of water provided to each service type (residential, commercial, etc.) to be recorded for the 2000 PWSASR. Prior to this, only the number of residential connections was reported. According to WWD’s 2000 report, 53% of the water supply is provided to the residential community, followed by commercial (29%).

Unaccounted for water was not reported on the annual reports until 2000, when the unaccounted for water was reported to be 8.78 MGY or 3% of the total water volume. This value is below the state's water conservation goal of less than 10 %.

4.2.4 Population Served

WWD reports that it served the same population for the summer and winter period, as the population remains stable throughout the year at 5,600 people (this same value has been reported since 1993). This value is based on the number of residential service connections and multiplying by 2.3, the average number of people per household. It was also reported on the 2000 PWSASR that WWD serves 500 connections in the town of Ashburnham.

Using the residential population served and dividing it by the number of gallons used per day (over a year) will yield the gallons per capita day (gpcd). The state's water conservation goal is to limit residential use to 80 gpcd. Using 2000 data, WWD is near the conservation goal, showing 76 gpcd of residential water consumption.

4.2.5 Water Conservation Measures

According to Mr. Murphy, WWD has a formal water conservation policy. The residents in the town of Winchendon operate under an "odd-even" water use restriction imposed by WWD during periods of drought. During this restriction, outside water use is prohibited every other day depending on the residents' street address.

4.2.6 Area Affected by Water Withdrawals

As noted above, the drainage area at the outlet of Upper Naukeag Lake is 2 mi^2. During the highest demand month, July, the total monthly withdraw is approximately 37.1 MG (or 0.93 cfs/day). Converting this average daily withdrawal rate to a flow per square mile at the lake outlet equates to 0.46 cfsm (0.93 cfs/2 mi^2). This represents a significantly large portion of the flow volume, and coupled with the Ashburnham Water Department (0.21 cfsm) is equivalent to 0.67 cfsm. In fact, a flow per square mile rate of 0.67 cfsm is considered high during July. Potential rationale for the high cfsm is that Upper Naukeag Lake is being drawn down over this period (although it was reported to operate as a stable pond during the summer), the geology of the area supports a large base flow (the lake is spring fed), or the meters were inaccurate.

Wastewater from Winchendon water users is sent to the Winchendon Water Pollution Control Facility located on the Millers River near the Tarbell Brook confluence. Thus, the affected river reaches include:

- the riverine reach between Upper and Lower Naukeag Lake,
- the Millers River from Sunset Lake to the Whitney Pond inlet and,
- the Millers River down to the Winchendon Water Pollution Control Facility.

4.3 Gardner Department of Public Works (Otter River Basin)

Public Water Supply No.: 2103000
Registration No.: 2-07-103.01

In 1991, the Gardner Department of Public Works (GDPW) registered for three surface water withdrawals with an average volume per day of 1.69 MGD (615.97 MGY). The original water sources included Crystal Lake, Cowee Pond, and Perley Brook. The layout and operation of the system is as follows: water flows by gravity from Cowee Pond to Perley Brook. Water is then pumped from Perley Brook to Crystal Lake on an as needed basis, where it is then pumped to the distribution system. Crystal Lake is the single source of water for distribution. Based on the PWSASR's, all three sources are considered to be active.

On September 20, 2001 MDEP issued a water withdrawal permit to GDPW. The new permit identifies two water withdrawal locations- Crystal Lake Reservoir and Otter River Well (also called Snake Pond). The permit authorizes the withdrawal of water, on average over the calendar year, at the rates shown in Table 4.3-1. The volumes reflected in Table 4.3-1 are in addition to the 1.69 MGD previously registered to the GDPW through the Water Management Act Program.

According to MDEP, the approved rate is going to be reduced to 573.5 MGY in 2004

Table 4.3-1: Gardner Department of Public Works, Permitted Volumes

Period	Daily Rate (MGD)	Registered Volume (MGD)	Total Authorized Withdrawal (MGD)	Total Annual (MGY)
09/20/2001-02/28/2003	0.49	1.69	2.18	795.70
03/01/2003-02/28/2008	0.56	1.69	2.25	821.25
03/01/2008-02/28/2013	0.63	1.69	2.32	846.80

Withdrawals from individual water sources are not to exceed the approved daily volumes listed in Table 4.3-2.

Table 4.3-2: Gardner Department of Public Works, Water Supply Source, Location, and Maximum Daily Withdrawal Rates

Source	Location	Maximum Daily Withdrawal Rates (MGD)
Otter River Well (Snake Pond)	off Airport Road	1.33*
Crystal Lake Reservoir	near Heywood Street	1.69**
* Maximum Daily Withdrawal Volume ** Annual average daily withdrawal volume authorized through December 31, 2003. Approval rate will be reduced to the 1.57 MGD firm yield volume on January 1, 2004.		

GDPW does not sell or purchase water from other vendors.

4.3.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.3.1-1 is the annual total withdrawal volume, average daily withdrawal, and peak daily withdrawal for the period 1993-2000. Annual water demand steadily increased from 1993 (697 MGY) before reaching a peak in 1999 (875 MGY), and then declining in 2000 (738 MGY). Prior to September 19, 2001, GDPW was registered to withdraw up to 615.97 MGY. From 1993 to 1999, GDPW annual withdrawal volume exceeded their registered limit (even accounting for the 0.1 MGD allowance). The MDEP, in their letter transmitting the permit recognized that past withdrawals have exceeded GDPW's registered volumes, but noted that the 2000 annual withdrawal volume (738 MGD) was lower than in previous years. MDEP states that this is ideally the result of improved water efficiency and the adoption of an outdoor water use restriction.

During the past eight years, the peak demand has occurred primarily during the summer period as follows: April (1), May (1), June (2), July (2), and August (2). The average difference between the average daily demand and peak demand over these years is approximately 1.72 MGD. The ratio of peak demand relative to average annual demand is 1.85. This ratio suggests that the GDPW's peak demand varies considerably relative to the average annual demand.

Shown in Figure 4.3.1-2 is a stacked bar graph depicting, by month, the water withdrawals for Crystal Lake, Perley Brook and Otter Creek Well (Snake Pond) for the period 1993-2000. As anticipated, water demands are highest in the summer (July- 72.7 MG/month), and lowest in the winter (February- 56.1 MG/month). Also, Figure 4.3.1-2 depicts the water source by month, with Crystal Lake providing the majority of water during July and August. As described below, Crystal Lake is drawn down in the summer to supplement water supply needs.

4.3.2 Storage Capacity

Per conversation with Dan Jellis (Earthtech, Consultants for GDPW), GDPW has three storage tanks with a total capacity of 4.75 MG, which are used to pressurize the system. In addition to storage tanks, Crystal Lake is drawn down in the summer to supplement demand.

Crystal Lake[17] is a man-made reservoir with a total surface area of 230 acres and a contributing drainage area of 3.75 mi^2. The total storage capacity of the reservoir is 768 MG (Crystal Lake only), with an available storage capacity above the intake of 357 MG. Relative to the average annual volume of water used (768 MG), Crystal Lake storage can provide approximately 46% of the annual volume, if needed. This represents a good portion of the total annual demand.

According to GDPW 1990 reports[18], it is possible to lower the intake to increase the capacity, which would deliver an additional 243 MGD (total of 600 MG or 78% of the annual demand).

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[17] The surface area and drainage area includes the combined system (Cowee Pond, Perley Brook Reservoir and Crystal Lake)

[18] As reported on "Water Management Act Registration Form C for a Surface Water Withdrawal (1990).

4.3.3 Customers/Unaccounted Water

Based on the 2000 PWSASR's, 53% of the water supply is used for residential use. All water use occurs within the town of Gardner, no water is conveyed out of the basin. Over the years 1998, 1999 and 2000 unaccounted for water constituted 35%, 33% and 24% of the total water supply, respectively. The MDEP noted in their September 2001 permit that GDPW's unaccounted-for-water use is relatively high. MDEP has required an ongoing program to repair, replace and recalibrate meters, a leak detection survey of the entire Gardner system, a water audit, and a program to retrofit City buildings with water saving devices.

4.3.4 Population Served

Shown in Figure 4.3.4-1 is the GDPW population served and the residential gpcd for the period 1993-2000 (no residential data was available for 1995). The residential population served is approximately 20,000 people and the population has remained relatively stable over the years. Average daily usage is 55 gpcd, which is below the state's water conservation goal of 80 gpcd for residential use.

4.3.5 Water Conservation Measures

GDPW has developed a Water Conservation Plan, which MDEP accepted as part of their permit. Gardner's service connections are 100% metered. As stated earlier, GDPW's unaccounted-for-water use is relatively high and MDEP has required various measures to identify leakage problems.

4.3.6 Area Affected by Water Withdrawals

The Otter River well is located adjacent to the Otter River near the Gardner Municipal Airport. As part of GDPW's recent permit they are required to evaluate and monitor the potential impacts on stream flow resulting from water withdrawals at the well. The well is located in a wetland area, and thus water withdrawals may impact wetland functions as well as decrease flows in the Otter River.

The Perley Brook and Crystal Lake complex is located on an unnamed tributary to the Otter River. The water withdrawals will likely reduce the magnitude of flow in the tributary. Water supply demands are supplemented in the summer by lowering Crystal Lake. According to GDPW's records, the watershed area at Crystal Lake is 3.75 mi^2 (this includes Cowee Pond, Perley Brook Reservoir and Crystal Lake). The average water supply demand in July is 72.7 MG[19] or 3.62 cfs/day. This equates to 0.97 cfsm, which is considered to be a high watershed yield for July, although the yield is artificially inflated due to Crystal Lake's summer drawdown.

Wastewater is collected at the Gardner WWTP and is discharged into the Otter River, which is located downstream of the well and Crystal Lake. The affected environment would consist of

[19] This volume includes Crystal Lake and Perley Brook- it does not include the Otter River well (Snake Pond).

the unnamed tributary from Crystal Lake as well as the tributary that drains near the Otter River Well. The magnitude of flow in these reaches would be reduced.

4.4 Westminster Water Department (Otter River Basin)

Public Water Supply No.: 2332000
Registration No.: 2-11-332.01

The Westminster Water Department (WeWD) registered to withdraw water from Meetinghouse Pond in 1991 for public water supply needs. Meetinghouse Pond is a distribution reservoir located in the Nashua River Basin (out-of-basin), just east of the Millers River Basin divide. Water is pumped as needed from Bickford Reservoir, located in the Chicopee River Basin, into Mare Meadow Reservoir, which straddles the Chicopee and Nashua River Basins. Water is pumped as needed from Mare Meadow into Meetinghouse Reservoir. The registered average daily withdrawal from Meetinghouse Pond is 0.243 MGD (88.646 MGY).

WeWD reports that they purchase all their water from the City of Fitchburg. In addition, WeWD sells water to Holmes Park Water District and Leino Park Water District. Holmes Park Water District is located in the Millers River Basin; Leino Park Water District is not. Additionally, there are only a few residential customers served in Westminster inside the Millers River Basin (Personal Communication, Bill Winturri, Director Westminster Department of Public Works).

The water used by Holmes Park is discharged via a septic system and thus from a water budget perspective is considered to be a net gain to the Millers River Basin. Most of the water delivered to customers is treated and discharged within the Nashua River Basin. Although the source of water is outside of the Millers River Basin, and only a small amount is discharged to the Millers River Basin, the same analysis for other water suppliers was repeated here simply for completeness. Because the water withdrawal occurs outside the Millers River Basin, the withdrawal location is not shown on Figure 4.0-2.

In 1991, WeWD applied for an amendment to withdraw water from Meetinghouse Pond. The MDEP approved the amendment on November 23, 1994. The permit authorizes the withdrawal of water, on average over the calendar year, at the rates shown in Table 4.4-1. The volumes reflected in Table 4.4-1 are in addition to the 0.24 MGD previously registered to the WeWD through the Water Management Act Program.

Table 4.4-1: Westminster Water Department, Permitted Volumes

Period	Daily Rate (MGD)	Registered Volume(MGD)	Total Authorized Withdrawal (MGD)	Total Annual (MGY)
03/01/1999-02/28/2004	0.25	0.24	0.49	178.85
03/01/2004-02/28/2009	0.28	0.24	0.52	189.80
03/01/2009-02/28/2014	0.32	0.24	0.56	204.40

Withdrawals from the Meetinghouse Pond withdrawal point are not to exceed the approved daily volume of 1.03 MGD.

4.4.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.4.1-1 is the annual withdrawal volume, average daily withdrawal, and peak daily withdrawal for the period 1993-2000. Annual water demand steadily decreased since 1994 (134 MGY) reaching a low in 2000 (79 MGY).

During the past eight years, the peak demand has occurred during the summer period as follows: June (4), July (2), and August (2). The average difference between the average daily demand and peak demand over these years is approximately 0.35 MGD. The ratio of peak demand relative to average annual demand is 2.19. This ratio suggests that the WeWD's peak demand varies considerably relative to the average annual demand.

Shown in Figure 4.4.1-2 is a bar graph depicting, by month, the average water withdrawals from Meetinghouse Pond for the period 1993-2000. Water demands are highest in the summer (July- 11.3 MG), and lowest in the winter (February- 7.5 MG).

4.4.2 Storage Capacity

WeWD maintains two above ground water storage tanks with capacities of 1 MG and 370,000 gallons.

4.4.3 Customers/Unaccounted Water

Based on the 2000 PWSASR's, 49% of the water supply is for residential use. Unaccounted-for-water is not reported on the annual reports.

4.4.4 Population Served

The residential population served is reported as 4,810 in the winter and 4,822 in the summer. Average daily usage, based on the summer population is 41gpcd, which is below the state's water conservation goal of 80 gpcd for residential use. Shown in Figure 4.4.4-1 is the population served and the residential gpcd for the period 1993-2000. The graph displays a steady downward trend in per capita water use since peaking at 67 gpcd in 1994.

4.4.5 Water Conservation Measures

WeWD has a Water Conservation Plan and Plan of Action, which includes leak detection and repair, meter replacements and education to customers detailing water saving tips. If the city of Fitchburg imposes water use restrictions, Westminster must also.

4.4.6 Area Affected by Water Withdrawals

There is no affected river reach since withdrawals occur outside the Millers River Basin. There is a net gain in water to the Millers River Basin as Holmes Park discharges to a septic system.

4.5 Templeton Water Department (Otter River Basin)

Public Water Supply No.: 2294000
Registration No.: 2-07-294.01

The Templeton Water Department (TWD) maintains four gravel packed wells for water supply withdrawals. The wells are identified as follows: Birch Hill Well #1, Birch Hill Well #2A, Otter River Well and Sawyer Street Well. When TWD registered for water withdrawals in 1991, their registered withdrawal was 0.53 MGD (195.03 MGY). Since then, a Water Withdrawal Permit was issued on August 4, 1994 that allowed for increased water withdrawal volumes in addition to the original registered amount. The volumes reflected in Table 4.5-1 are in addition to the 0.53 MGD previously registered to the TWD through the Water Management Act Program.

Table 4.5-1: Templeton Water Department, Permitted Volumes

Period	Daily Rate (MGD)	Registered Volume (MGD)	Total Authorized Withdrawal (MGD)	Total Annual (MGY)
08/04/1994-02/28/1998	0.25	0.53	0.78	284.70
03/01/1998-02/28/2003	0.31	0.53	0.84	306.60
03/01/2003-02/28/2008	0.38	0.53	0.91	332.15
03/01/2008-02/28/2013	0.42	0.53	0.95	346.75

4.5.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.5.1-1 is the annual total withdrawal volume (MGY), average daily withdrawal (MGD), and peak withdrawal (MGD) for the period 1993-2000. The annual withdrawal volume from 1993-1998 has been relatively consistent, ranging from 248 MGY to 296 MGY, however in 1999 and 2000 the annual demand dropped to 174 MGY. For the 1993-2000 period, the Sawyer Street Well was the leading provider of water to TWD. It should be noted that Birch Hill Well #1 and #2 use the same meter to measure flow. The wells do not operate concurrently, although TWD reports the metered flow as the sum of Wells #1 and #2 (Personal Communication, Ron Davan, Superintendent).

Over the past eight years, the peak demand has occurred three times in April, twice in March, and once each in July, August and November. The average difference between the average daily demand and peak demand over the last eight years is approximately 0.68 MGD. The ratio of peak demand relative to average annual demand is 1.90[20]. This ratio suggests that the TWD peak demand varies somewhat relative to the average annual demand.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.5.1-2 is a stacked bar graph depicting, by month, the water withdrawals for the four wells utilized by TWD. The average monthly water usage does not vary considerably ranging from a low of 19.2 MGD in February to 23.5 MGD in June.

[20] When computing average peak demand and average annual demand, 2000 data was excluded due to reporting errors.

4.5.2 Storage Capacity

The system's treated water storage capacity was previously 1 MG, which was stored in two above ground steel storage tanks. In 2002, a new 0.75 MG storage tank was added to the storage system for the primary purpose of increased fire protection. All of the water supply is obtained from wells; there are no surface storage reservoirs in the system that could be used to supplement high demand periods.

4.5.3 Customers/Unaccounted Water

Based on the 2000 PWSASR's, 75% of the water supply is for residential use. All water use occurs within the town of Templeton, however a portion of the town is located outside of the Millers River Basin. Additionally, many residents of the town utilize well water (personal communication, Mr. Davan, Superintendent).

The 2000 PWSASR does not report any unaccounted for water. Previous to this, unaccounted-for-water was very high ranging from 25% in 1995 to over 40% in 1999. Per discussions with Mr. Davan, the unaccounted-for-water reported from 1993-1999 was inaccurately high due to different billing rates. Apparently, the unaccounted-for-water was determined based upon the amount of water sales, but the various rates for different customers were not taken into account. Additionally, Mr. Davan indicated that many of the water meters were replaced in 2001. An analysis revealed that the old meters under-reported the water use by up to 21 MG per year. The unaccounted-for-water in 2001 was reported to be around 12%.

4.5.4 Population Served

Since 1993 the population served has increased from 4,980 to 6,987. According to the Mr. Davan, these figures represent the total town population and take into consideration those people using well water. The number of residential connections in 2000 and 2001 was 1,796 and 1,819, respectively. Other towns have used the State's average number of people per household of 2.3 to convert the number of residential connections into population served. Using this method, the per capita water consumption in 2000 was around 70 gpcd. This is just below the state's water conservation goal of 80 gpcd for residential use. Previously, the per capita water consumption was underestimated because of the over-reporting of the population served. Shown in Figure 4.5.4-1 is the population served and the residential gpcd for the period 1993-2000.

4.5.5 Water Conservation Measures

No formal water conservation policy is currently in place, however, a meter replacement program was completed in 2001 resulting in increased reporting accuracy.

4.5.6 Area Affected by Water Withdrawals

All of the wells utilized for public water supply for the town of Templeton are located very close to the Otter River. Birch Hill GP Well #1 and #2 are located near the center of Baldwinville in close proximity to the Otter River. The Sawyer Hill Well is located on an unnamed tributary to the Otter River, and the Otter River well is also located close to the Otter River.

Wastewater from the TWD water supply is sent to the Templeton WWTP, which is located upstream of the Birch Hill Wells, close to the Otter River well, and downstream of the Sawyer Hill Well. The riverine reaches affected by the water withdrawals include the Otter River, and the unnamed tributary (which includes the Sawyer Hill Well). Although a portion of the water supply serves customers outside the Millers River Basin, it is assumed that 50% of the water is returned to the basin via the Templeton WWTP or otherwise remains in-basin. Some water is assumed to be a net loss due to lawn watering, car washing, filling swimming pools, etc.

4.6 Seaman Paper Company (Otter River Basin)

Registration No.: 2-07-294.02

Seaman Paper Company (SPC) makes lightweight wrapping tissue among other products. In 1991, SPC registered for water supply withdrawals and was authorized to withdraw an average volume per day of 1.19 MGD (or 436 MGY). The registration authorizes two withdrawal points- a well located in Templeton and a surface water withdrawal from the Otter River. The one surface water withdrawal includes two pumps ("Kinney" and "Clearwell"). Since both pumps are individually metered SPC provides the individual withdrawal. Also, the surface and groundwater withdrawals are shown at the same location on Figure 4.0-2.

4.6.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.6.1-1 is the annual total withdrawal volume (MGY) and average daily withdrawal (MGD) for the period 1993-1999. Since the withdrawal is used for industrial purposes there is no peak withdrawal reported on the Registered & Permitted Withdrawals Annual Reports. As the graph depicts the annual withdrawal volume has been relatively consistent over the past years, ranging from 345 MGY in 1994 to 399 MGY in 1997. Likewise, the average daily withdrawal for the period 1993-1999 is also very consistent ranging from 0.95 MGD to 1.09 MGD. These values are close to the registered average daily allowance of 1.19 MGD. The majority of water is obtained from the surface water withdrawals; very little is taken from the groundwater source. In fact, SPC has not utilized the well since 1996.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.6.1-2 is a stacked bar graph depicting, by month, the water withdrawals from the Otter River. Similar to the annual water usage, the monthly water usage is very stable, which is consistent with industrial use.

4.6.2 Water Conservation Measures

No water conservation measures are indicated, however, George Jones of SPC indicated that they recycle approximately 200,000 to 300,000 GPD.

4.6.3 Area Affected by Water Withdrawals

SPC withdraws water at the Otter Dam, uses it for industrial purposes, and then returns the flow after treatment to the Otter River. The withdrawals are not used for consumptive purposes, although some evaporative losses occur during the manufacturing process. There is a short stretch (roughly 200 yards) of the Otter River between the surface water withdrawal location and SPC's NPDES discharge point that is affected by the withdrawal. The magnitude of flow in this river reach is reduced due to the withdrawal.

4.7 American Tissue Mills (Otter River Basin)

Registration No.: 1-07-091.02

Historically, American Tissue Mills of Mass., Inc. used water for industrial purposes from the Otter River and Depot Pond in Baldwinville. In 1991, American Tissue Mills registered for water supply withdrawals and were authorized to withdraw an average volume per day of 2.02 MGD (or 736.32 MGY). The mill was shut down and water withdrawals ceased in 1995.

4.7.1 Annual and Monthly Withdrawal Volumes

Although the database is limited, Figure 4.7.1-1 depicts the annual total withdrawal volume (MGY) and average daily withdrawal (MGD) for the period 1994-1995. The annual withdrawal volume by American Tissue Mills during the two years of record was 743 MGY in 1994 and 703 MGY in 1995.

On the Registered & Permitted Withdrawals Annual Reports, the days of operation in 1994 and 1995 were reported to be 298 and 248, respectively, thus withdrawals do not occur continuously. Likewise, the average daily demand was reported to be 2.49 MGD for 1994 and 2.84 MGD for 1995, which exceeded their registered average daily allowance of 2.02 MGD.

Shown in Figure 4.7.1-2 is a stacked bar graph depicting, by month, the water withdrawals from the two withdrawal points- Otter River and Depot Pond. The average monthly withdrawal based upon years 1994 and 1995 show that September had the highest average withdrawal of 80.7 MG and November had the lowest of 46.6 MG. Most of the water was taken from the Otter River.

4.7.2 Water Conservation Measures

It is unknown what type of water conservation measures were implemented when the mill was operational.

4.7.3 Area Affected by Water Withdrawals

Since the facility has been out of operation since 1995, no contact could be made with individuals that would know where processing water was treated and returned to the river. Because of its very close proximity, it is possible that the Templeton WWTP treated the water used by American Tissue. The affected riverine reach (before the mill was closed) would include the small tributary leading from Depot Pond to the Otter River, as well as the Otter River itself. The magnitude of flow in these reaches would be reduced due to the withdrawals.

4.8 Athol Department of Public Works-Water Division (Tully River)

Public Water Supply No.: 2015000
Registration No.: 2-07-015.01

The Athol Department of Public Works- Water Division (ADPW) originally registered for the use of two surface and one groundwater water supply withdrawals. In 1991, ADPW registered for water supply withdrawals and were authorized to withdraw an average volume per day of 1.04 MGD (or 379.66 MGY). Withdrawal points were located at the South Street Well off Jones Street, Phillipston Reservoir off Route 2A and Newton Reservoir off South Royalston Road. Thousand Acre Reservoir and Lake Ellis are registered as emergency sources. Based on conversations with Andrew Tessier, Water Treatment Operator, Newton and Phillipston Reservoirs are now disconnected from the system, although the South Street Well is still active. The South Street Well is exercised once a week (pumped to maintain operability) and used primarily as a backup to the Tully wells (the new water supply sources used since 2000).

Since 1991, a Water Withdrawal Permit was reissued on June 19, 2000. The new permit authorized no increase in system-wide water withdrawal volumes, however the permit did identify three alternative water withdrawal sources. These sources are three wells located off Pequoig Avenue and are referred to as Tully Well #1, #2 and #3.

The MDEP indicates that the shift in water sources is considered to provide a significant environmental gain through the increase of flows from Buckman Brook and Thousand Acre Brook as a result of the removal of Newton Reservoir and Phillipston Reservoir from active service. According to the 2000 PWSASR, these two reservoirs were last utilized in April 2000.

Withdrawals from individual withdrawal points are not to exceed the approved daily volumes listed in Table 4.8-1. It should be noted that the three wells identified in Table 4.8-1 can withdraw a maximum of 3.29 MGD in a day, however, the average annual withdrawal can not exceed 1.04 MGD.

Table 4.8-1: Athol Department of Public Works-Water Division- Water Supply Source, Location, and Maximum Daily Withdrawal Rates

Source	Location	Maximum Daily Withdrawal Rates (MGD)
Tully Well #1	off Pequoig Avenue	1.37 MGD
Tully Well #2	off Pequoig Avenue	1.11 MGD
Tully Well #3	off Pequoig Avenue	0.81 MGD
Note: The combined maximum daily withdrawal volume from these wells cannot exceed 3.29 MGD		

Based on the period 1993-2000, ADPW has not purchased water from other water users; however, they consistently sell water to Orange Water Department (OWD). Based on the period 1995-2000, ADPW has sold approximately 3.5 MG of water annually to OWD.

4.8.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.8.1-1 is the annual total withdrawal volume and average daily withdrawal for the period 1993-2000. Peak withdrawal is shown for the period 1995-2000 (data was unavailable for 1993-94). As the graph depicts the annual withdrawal volume has been fairly consistent over the past few years, with the exception of 2000 when water withdrawal sources were changed to the Tully Wells. Prior to 2000, annual withdrawal volume ranged from 342 MGY to 373 MGY and in 2000 dropped to 308 MGY. Note that in 1995-1997, ADPW used between 19 and 22 MGY to backwash rapid sand filters at the Hillside Terrace Filtration Facility and the South Street Well activated carbon units. During these three years, the annual reports do not consider the backwash water when computing the average daily consumption for the whole system. For the period 1993-1999, water was taken in a somewhat even distribution from each of the three water sources.

During the past six years, the peak demand has occurred throughout the year as follows: May (1), June (2), July (1), August (1) and once in December 2000. The average difference between the average daily demand and peak demand over these years is approximately 0.41 MGD. The ratio of peak demand relative to average annual demand is 1.44. This ratio suggests that the ADPW's peak demand varies slightly relative to the average annual demand.

Shown in Figure 4.8.1-2 is a stacked bar graph depicting, by month, the water withdrawals for South Street Well, Phillipston Reservoir and Newton Reservoir for the period 1993-1999. Withdrawal data for 2000 was not used because ADPW removed the two reservoirs from service, replacing them with the Tully Wells. The average monthly water usage varies seasonally ranging from a low of 26 MGD in February to 33.6 MGD in June. As Figure 4.2.1-2 depicts water use increases during the summer period (June-August).

4.8.2 Storage Capacity

Mr. Tessier indicated that ADPW has three storage tanks in the system with a total capacity of 2 MG, which are used to pressurize the system. The amount of storage capacity (2 MG) relative to the average annual demand (352 MGY) is minimal and would not augment flows during low summer flow periods. As noted above, the Phillipston and Newton Reservoirs are currently disconnected from the system and thus should not be considered as useable storage capacity.

4.8.3 Customers/Unaccounted Water

Based on the 2000 PWSASR's, 66% of the water supply is for residential and mobile home park use. All water use occurs within the town of Athol, no water is conveyed out of the basin. Over the years 1998, 1999 and 2000 unaccounted-for-water constituted 16%, 14% and 8% of the total water supply, respectively.

4.8.4 Population Served

Since 1995 ADPW has reported the same population served throughout the year; 9,300 people in the winter and summer. Shown in Figure 4.8.4-1 is the population served and the residential gpcd for the period 1995-2000. Based on the average residential population served over this period, the average residential use in gallons per capita day is 61 gpcd, which is below the state's water conservation goal of 80 gpcd for residential use.

4.8.5 Water Conservation Measures

ADPW currently has a water conservation policy in place, which was accepted by the MDEP when the water withdrawal permit was renewed in 2000. Water conservation measures include service meters, which were to be installed on 100% of the system by June 19, 2002, with all meters requiring annual calibration. As part of the plan, Athol must conduct a full leak detection survey biennially with reporting on leak detection and repairs.

4.8.6 Area Affected by Water Withdrawals

Removing Phillipston and Newton Reservoirs from the system should increase flows in the Thousand Acre Brook and Buckman Brook, respectively. The three new wells are located adjacent to the Tully River below the East and West Branch confluence, and just upstream of the Millers River confluence. The potential affect of water withdrawals is a reduction in the magnitude of Tully River flow from the point of withdrawal to the confluence with the Millers River, however, other upstream regulation will also impact flow in this river segment. Operation of the Corps Tully Lake Dam affects the timing and magnitude of streamflow in this reach. Water pumped from the Tully wells is used by water users in Athol, is eventually treated at the Athol WWTP, and is discharged to the Millers River just west of Athol.

In the MDEP permit, it states, "The Department received a number of comments concerning potential impact of withdrawals on both the Tully River and the wetlands surrounding the wellfield. The primary species of concern was identified as the state-protected Wood Turtle, which requires a perennial stream habitat, and in particular requires that winter flows be sustained for over-wintering turtles. The Department is satisfied that the withdrawal impacts from this project are minimal and are mitigated by the fact that actual withdrawal volumes will be significantly below those authorized from this source".

4.9 Orange Water Department (Lake Rohunta and North Pond Brook)

Public Water Supply No.: 1223000
Registration No.: 1-07-223.01

The Orange Water Department (OWD) maintains three gravel packed wells for water supply withdrawals. Wells #1 and #2 are located adjacent to North Pond Brook, a small tributary to the Millers River. Well #3 is located west of Lake Rohunta.

In 1991, OWD registered for water supply withdrawals and were authorized to withdraw an average volume per day of 0.63 MGD (or 230.51 MGY). Since 1991, a Water Withdrawal Permit was reissued on September 29, 2000. The permit authorizes the withdrawal of water, on average over the calendar year, at the rates shown in Table 4.9-1. The volumes reflected in Table 4.9-1 are in addition to the 0.63 MGD previously registered to the OWD through the Water Management Act Program.

Table 4.9-1: Orange Water Department, Permitted Volumes

Period	Daily Rate (MGD)	Registered Volume (MGD)	Total Authorized Withdrawal (MGD)	Total Annual (MGY)
07/14/1994-02/28/1998	0.27	0.63	0.90	328.50
03/01/1998-02/28/2003	0.30	0.63	0.93	339.45
03/01/2003-02/28/2008	0.32	0.63	0.95	346.75
03/01/2008-02/28/2013	0.33	0.63	0.96	350.40

Withdrawals from individual withdrawal points are not to exceed the approved daily volumes listed in Table 4.9-2.

Table 4.9-2: Orange Water Department, Water Supply Source, Location, and Maximum Daily Withdrawal Rates

Source	Location	Maximum Daily Withdrawal Rates (MGD)
Minute Tapica Well (Gravel Pack Well #1)	off Holtshire Road	0.360 MGD
MaGee's Meadow Well (Gravel Pack Well #2)	off West River Street	0.520 MGD
Daniel Shays Highway Well (Gravel Pack Well #3)	off Daniel Shay's Highway (Route 202)	0.837 MGD

Based on the period 1993-2000, OWD purchased water from the Athol Department of Public Works- Water Division. Over this period, the average annual purchase of water was 4.1 MGY or 0.01 MGD.

4.9.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.9.1-1 is the annual total withdrawal volume (MGY), average daily withdrawal (MGD), and peak withdrawal (MGD) for the period 1993-2000. As the graph depicts the annual withdrawal volume (including the small amount of purchased water) has been relatively consistent over the past few years, ranging from 223 MGY to 252 MGY. In addition, the majority of the annual withdrawal is obtained from Well #3, followed by Well #2, purchased water, and rarely used Well #1.

Over these eight years, the peak demand has occurred randomly throughout the year as follows: February (2), March (1), April (2), July (1), August (1) and October (1). The average difference between the average daily demand and peak demand over the last eight years is approximately 0.38 MGD. The ratio of peak demand relative to average annual demand is 1.59. This ratio suggests that the OWD peak demand varies somewhat relative to the average annual demand.

Shown in Figure 4.9.1-2 is a stacked bar graph depicting, by month, the water withdrawals for Wells #1-#3, plus purchased water. Similar to the annual water usage, the monthly water usage does not vary ranging from a low of 18.3 MGD in November to 21.9 MGD in July. Typically, water usage increases in the summer due to watering lawns, agricultural use, car washes, filling swimming pools, etc, however, this trend is not evident for OWD.

4.9.2 Storage Capacity

OWD maintains two concrete storage tanks; the North Tank is located near North Main Street and the South Tank is located near Walnut Hill Road. Each tank has a storage capacity of 1 MG for a total capacity of 2 MG. The amount of storage capacity (2 MG) relative to the average annual demand (238 MGY) is minimal and would not substantially augment flows during low summer flow periods.

4.9.3 Customers/Unaccounted Water

In 2000, 39% of the water supply was provided to the residential community, followed by commercial (12%). Also, in 2000 19% of OWD's water supply fell under the unaccounted-for-water category. This value exceeds the state's water conservation goal of less than 10 %. The MDEP requires that water suppliers having 15% or greater unaccounted for water indicate the possible reasons. The primary causes of unaccounted-for-water were leaks, followed by fire protection (hydrant flushing) and other (pipeline flushing).

4.9.4 Population Served

OWD reports the same population for the summer and winter period, as the population remains stable throughout the year. As shown in Figure 4.9.4-1 the population served by OWD has steadily decreased from 5,500 in 1993 to 3,890 in 2000. Interestingly, the rate of water consumption has remained steady throughout the same 1993 to 2000 period, presumably due to increased water use by users other than the residential community (or the method for computing the population served has changed).

The state's water conservation goal is to limit residential use to 80 gpcd. As shown on Figure 4.9.4-1, OWD is within the conservation goal, averaging around 71 gpcd over the last few years.

4.9.5 Water Conservation Measures

OWD currently does not have a water conservation policy in place. There is currently no bylaw or ordinance to implement mandatory outside water use restrictions. OWD does mail to their customers tips for conserving and saving water.

4.9.6 Area Affected by Water Withdrawals

Gravel packed Well #1 and #2 are located near North Pond Brook below Lake Mattawa, which is a tributary to the Millers River. Gravel packed Well #3 is located west of Lake Rohunta, also a tributary to the Millers River. The water supply from these wells is delivered to water users in

Orange, eventually collected and treated at the Orange WWTP, and then discharged to the Millers River just below the New Home Dam. The affected river segments include:

- North Pond Brook from the well locations (Well #1, #2) to the Millers River confluence, and a short portion of the Millers River down to the Orange WWTP (this Millers River reach would not be greatly affected given the withdrawal volume relative to the total flow volume).
- Initially, it is assumed that Well #3 withdraws water from within the Lake Rohunta drainage area, although no data is available to support this assumption. Mr. Richard Kilhart indicated that based on pump tests for the state, Well #3 does affect flow in Lake Rohunta or Cold Brook. Therefore, it was assumed that Well #3 withdraws from a confined aquifer.

Since the monthly water withdrawal is relatively constant, flows in North Pond Brook are not likely affected on a seasonal basis; however, the withdrawal may reduce the magnitude of flow in North Pond Brook (Wells #1 and #2 both withdraw water from the North Pond Brook aquifer which lies immediately south of the Millers River on the west side of the Town of Orange). Other than these two wells, any flow manipulation at Lake Mattawa may also affect flow in North Pond Brook.

4.10 Erving Paper Mills (Millers River)

Registration No.: 1-07-091.02

Erving Paper manufactures napkins and specialty paper products such as placemats, banquet rolls, table covers, white and color napkins, seasonal designs and special prints. Erving Paper Mills is registered to withdraw 2.66 MGD (969.66 MGY) for industrial use. The withdrawal points are from two wells on East Main Street in Erving and one additional surface water withdrawal from the Millers River.

4.10.1 Annual and Monthly Withdrawal Volumes

Figure 4.10.1-1 depicts the annual total withdrawal volume (MGY) and average daily withdrawal (MGD) for the period 1993-2000 (note that although there are two official groundwater withdrawal points, the volume of water taken from these wells is shown as a single value in the reports). The annual withdrawal volume by Erving Paper Mills has varied somewhat over the past years, ranging from 672 MGY in 1993 to 820 MGY in 1999. Likewise, the average daily withdrawal for the period of record is variable, ranging from 1.84 MGD to 2.25 MGD. These values are below the registered average daily allowance of 2.66 MGD.

Shown in Figure 4.10.1-2 is a stacked bar graph depicting, by month, the water withdrawals from the Millers River and the groundwater well. Unlike the annual water usage, the monthly water usage does not vary with nearly all of the water taken from the Millers River. Mill officials also reported that the groundwater withdrawal is used for drinking water, whereas the Millers River surface water withdrawal is used for industrial uses.

4.10.2 Water Conservation Measures

Paper machine water is recycled and used as make-up in the de-inking process. On average, Erving Paper Mills sends 2.0 MG to the Erving Center WWTP, which is subsequently discharged to the Millers River after treatment and removal of solids. The mill consumes some water, but the bulk (2.0 MGD of 2.66 MGD) is sent to the WWTP (Personal Communication, Marguerite McCollett, Environmental and Process Engineer).

4.10.3 Area Affected by Water Withdrawals

The latitude and longitude of the withdrawal points are reported as the same for the two wells. No records of the surface water withdrawal coordinates were available. Marguerite McCollett indicated that the Millers River surface water withdrawal was located in close proximity to the well withdrawal. Thus, Figure 4.0-2 shows only one withdrawal location for Erving Paper Mills.

Water used by the mill is sent to the Erving Center WWTP, which is located immediately downstream of the mill. Thus, the impacted riverine reach extends from the withdrawal point to the WWTP. The magnitude of daily withdrawal (2.1 MGD or roughly 3.2 cfs) represents a very small fraction of the total flow in this reach (the drainage area at the USGS gage in Erving is 372 mi^2, the average daily flow is approximately 641 cfs).

4.11 International Paper-Strathmore (Millers River Basin)

Registration No.: 1-07-192.01

Historically, the International Paper Company-Strathmore (IP) paper mill used water for industrial purposes from the Millers River and from one groundwater well. In 1991, IP registered for water supply withdrawals and was authorized to withdraw an average volume per day of 0.14 MGD (or 50.45 MGY). A Water Withdrawal Permit was issued on May 26, 1994 in response to a request from IP to remove the existing groundwater withdrawal point from the registration. Additionally the permit authorized increases in water withdrawals, on average over the calendar year, at the rates shown in Table 4.11-1. The volumes reflected in Table 4.11-1 include the 0.14 MGD previously registered to IP through the Water Management Act Program.

Table 4.11-1: International Paper, Permitted Volumes

Period	Daily Rate (MGD)	Registered Volume (MGD)	Total Authorized Withdrawal (MGD)	Total Annual (MGY)
05/26/1994-02/28/1998	0.61	0.14	0.75	273.75
03/01/1998-02/28/2003	0.61	0.14	0.75	273.75
03/01/2003-02/28/2008	0.61	0.14	0.75	273.75
03/01/2008-02/28/2013	0.61	0.14	0.75	273.75

Withdrawals from the Millers River are not to exceed the approved daily volume of 1.44 MGD. In 1998, IP requested to relocate its water intake structure on the Millers River approximately 200 feet upstream from the existing intake. In response, MDEP granted the request, with a requirement to install a fish barrier to protect the resident fish population. The 5-year review of IP's permit pursuant to the Water Management Act was completed in 2000 with no changes in water withdrawal locations or amounts.

As of August 31, 2000 the International Paper –Millers Falls facility ceased production. It is assumed that water withdrawals were also ceased, as the 2000 PWSASR indicated no withdrawals from September 1 to December 31, 2000.

4.11.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.11.1-1 is IP's annual total withdrawal volume (MGY) and average daily withdrawal (MGD) for the period 1993-2000. As the graph depicts the annual withdrawal volume has been relatively consistent over the past years, ranging from 115 MGY to 138 MGY. Annual water use dropped off in 2000 due to the facility ceasing production on August 31, 2000.

The average daily withdrawal for the period 1993-1999 is also very consistent ranging from 0.32 MGD to 0.38 MGD. Note that these values are significantly less than the daily allowance of 0.75 MGD.

Shown in Figure 4.11.1-2 is a bar graph depicting, by month, IP's water withdrawals from the Millers River. Similar to the annual water usage, the monthly water usage did not vary much ranging from a low of 8.5 MGD in December to a high of 11.0 MGD in March.

4.11.2 Water Conservation Measures

As a condition of the MDEP permit, IP was required to submit a Water Conservation and Implementation Plan that was to include an audit of all water systems, the analysis of the feasibility of water re-use/recycling, upgrading machinery, a leak detection program and an employee awareness program. IP had taken action to reduce its water usage by incorporating various water re-use and recycling practices into its water conservation program.

4.11.3 Area Affected by Water Withdrawals

Processing water previously used by IP was eventually sent to the Erving POTW #1 before returning to the Millers River. The WWTP is located downstream of the withdrawal point, thus the magnitude of flow in the Millers River was reduced in the river reach between the withdrawal point and the WWTP return. The magnitude of daily withdrawal (0.32 MGD or roughly 0.5 cfs) represents a very small fraction of the total flow in the reach (the drainage area at the USGS gage in Erving is 372 mi^2, the average daily flow is approximately 641 cfs).

4.12 Summary of Unaccounted for Water and Residential Use

Shown in Table 4.12-1 is a summary of the unaccounted for water and residential water usage for public water suppliers in the Millers River Basin. The purpose of this table is to highlight those suppliers that do not meet the water conservation benchmarks specified by MDEM of 1) residential gpcd of 70-80 or less, and 2) unaccounted for water of 10-15% or less.

Table 4.12-1. Summary of Unaccounted for Water and Residential Use for Public Water Suppliers

Public Water Supplier	Unaccounted for Water (year % is based upon)	Residential Gallons Per Capita Day (year gpcd is based upon)	Water Conservation Plan Status
Ashburnham	13% (1993-2000)	[21]26 gpcd (1993-2000)	No
Winchendon	3% (2000)	76 gpcd (2000)	Yes
Gardner	35% (1998) 33% (1999) 24% (2000)	55 gpcd (1993-2000, absent 1995)	Yes
Templeton	12% (2001)	70 gpcd (2001)	No
Athol	16% (1998) 14% (1999) 8% (2000)	61 gpcd	Yes
Orange	19% (2001)	71 gpcd	No
Shaded cells indicate public water suppliers that do not meet the water conservation benchmarks specified by MDEM of 1) Residential GPCD of 80 or less, and 2) Unaccounted for water of 10% or less.			

Based on Table 4.12-1, five of the water suppliers exceed the unaccounted for water goal of 10-15% or less. It is also interesting to note that of the six in-basin public water suppliers three have water conservation plans, and the remaining three do not. Later in this report, future water supply demands are forecasted. It will be imperative that before additional supplies are tapped, water conservation measures should be implemented to lessen future demands.

It should be noted that water conservation measures are required under the Water Management Act. Water systems that have only a registration are required to develop a Water Conservation Plan upon their next registration renewal. Water users applying for a permit are required to submit and comply with Water Conservation Plans as well.

4.13 Summary of Water Withdrawals by Subbasin

Subbasins containing water withdrawals are examined below to summarize the cumulative effect of water withdrawals.

<u>Otter River Basin</u>

The Otter River Basin contains four water registered water withdrawals, although American Tissue's withdrawal has been inactive since 1995. The Otter River Basin at the confluence with the Millers River has a drainage area of approximately 60.54 mi^2. Shown in Figure 4.13-1 is the average monthly withdrawal for each water user on a cfs basis. The largest withdrawals are from the Gardner Water Department. The total average monthly withdrawal from the Otter River Basin ranges from approximately 8-10 cfs (or 0.13 to 0.16 cfsm). Eliminating American Tissue

[21] As noted above, it is very unlikely that residential water use is 26 gpcd. Typically usage is higher and it is likely that the estimated population was inaccurately high.

reduces the average monthly withdrawal to approximately 5.5-6.5 cfs. Although, the American Tissue registration and permit are not currently in use, presumably a future user could transfer the permit at this location.

Upper Naukeag Lake Basin

Both the towns of Ashburnham and Winchendon withdraw water from Upper Naukeag Lake, which has a drainage area of approximately 2 mi^2. Shown in Figure 4.13-2 is the average monthly withdrawal for each water user. The average monthly withdrawal from Upper Naukeag Lake ranges from approximately 1.75 to 2.25 cfs (0.88 to 1.12 cfsm), with the largest withdrawals occurring in the summer. The average monthly withdrawal volumes are considered high, given a drainage area of only 2 mi^2, however, as stated earlier the lake is spring-fed. Historical and more recent reports have suggested that the safe yield of Upper Naukeag Lake ranges between 1.0 MGD (1.55 cfs- old reports) to as high as 1.7 MGD (2.63 cfs- new reports).

Tully River Basin

The Athol Department of Public Works has three wells located near the Tully River's confluence with the Millers River. The drainage area of the Tully River at the confluence with the Millers River is approximately 72.8 mi^2. Shown in Figure 4.13-3 is the average monthly withdrawal volume, which shows water usage ranging from 1.3-1.6 cfs (0.018-0.022 cfsm) per month.

North Pond Brook Basin

The Orange Water Department has two wells (Wells 1 and 2) located in the North Pond Brook drainage area. The drainage area of North Pond Brook at the Millers River confluence is approximately 1.98 mi^2. Shown in Figure 4.13-4 is the average monthly withdrawal volume, which shows withdrawals ranging from 0.21 to 0.27 cfs (0.11-0.14 cfsm) per month.

Millers River Basin

All water withdrawals in the Millers River Basin are summarized in Figure 4.13-5. The largest water withdrawals are from the Gardner Water Department, American Tissue (out of operation since 1995) and Erving Paper Mills. The drainage area of the Millers River is approximately 388.87 mi^2 (based on the USGS Streamstats program). Average monthly withdrawal rates are consistent throughout the year, averaging near 17 cfs (0.04 cfsm). Lastly shown in Figure 4.13-6 is the average annual withdrawal rate categorized by water user.

Later in is this report, each of these subbasins is examined further to determine whether a given river reach is considered stressed. The withdrawal data, in conjunction with the NPDES discharge data, was used to determine the net gain (+) or loss (-) of water from the subbasin.

5.0 Forecasted Future Water Supply Demands

Forecasting future population and water supply demand is a complex process. There is no exact science although sophisticated mathematical equations are often used. Usually forecasts are based on past census records for the area or by projecting past trends into the future. The purpose of forecasting future water supply demands is to determine the amount of water expected to be withdrawn from the Millers River Basin. In addition, existing water withdrawal sources may require increased withdrawals (after water conservation measures are adopted) to support future demands, which could further impact environmental resources. Also, new water withdrawal locations might be identified, which could also impact environmental resources. In this section, future water supply needs are estimated using population and current water supply demands.

The Massachusetts Water Resources Commission (MWRC) has developed two methods (Method 1 and 2) to predict future public water supply demands that rely upon past water supply demand, population estimates, and other information. The selected method is dependent on the amount of available data and other parameters as described below. Either Method 1 or 2 was used to estimate future water supply demands in the years 2005, 2010 and 2020. The purpose for making these estimates is to identify the overall demand, and to estimate potential future effects on riverine reaches due to the reduction in flow.

Method 1

Method 1 uses a disaggregated[22] approach based on the most recent three years of water use data (called base demand) for each community in the study area. The three main water use categories for each community are residential, non-residential (including commercial, industrial, agricultural, municipal), and unaccounted-for-water (UAW).

Method 1 is used to estimate water use forecasts for those communities which:

- are able to provide sufficient disaggregated water use data,
- show a residential gallons per capita daily use of 80 gpcd or less, and
- have an UAW factor of 15% or less.

The methodology assumes that if the existing UAW is 10 % or lower, the existing percentage will continue in the future. If the UAW is greater than 10%, it is assumed that there will be a reduction in UAW during the planning period to reach 10%.

For communities that have insufficient data to develop a disaggregated water needs forecast, have a residential gpcd over 80, or a high percentage of UAW, Method 2 is used.

Method 2

Due to a low percentage of metering and/or inaccurate metering, a number of communities do not have adequate data to permit a disaggregated water use forecast, and therefore Method 2 is used.

[22] Disaggregated means that water supply records are broken down into residential, non-residential (such as commercial, industrial, etc) and unaccounted-for-water, etc. Many water suppliers do not have disaggregated data due to the lack of metering or in some cases inaccurate metering.

Method 2 assumes that the daily water use of any additional population growth will have a gpcd of no more than 70, and makes no allowance for UAW. Therefore, towns having a high residential gpcd (greater than 80) and/or a high UAW component (greater than 15%) are subject to Method 2.

5.1 Water Supply Forecast- Data Sources

In forecasting future water supply demands, data from the last three years (1999-2001) of PWSASR's were used. The statistical reports contain information on residential, non-residential and UAW. The consistency of the disaggregated water use over the last three years was used to determine whether Method 1 or 2 would be applied.

Consideration was given to the community population in each town served by a Public Water Supplier. The number of people in each community serviced by a public water supplier was obtained directly from the PWSASR's. Population is often determined by the number of service connections multiplied by the average number of people per household in that town. The actual town population was obtained from 2000 federal census data. It was assumed that the percent of the population served by the water supplier in each community would remain constant as the total town population increased.

Population estimates for the years 2005 and 2010 were obtained from the Massachusetts Institute of Social and Economic Research (MISER) census data for each town that has a public water supply in the Millers River Basin. MISER provides three levels of growth projections through 2010- low-level, mid-level and high-level. The 2000 town population was compared to each level of MISER projections for that year, and the most accurate projections were used. Most towns displayed mid-level growth, however, Gardner and Ashburnham showed a pattern of low-level growth and Westminster showed high-level growth. Because MISER only projects population estimates to 2010, the 2020 population was estimated using the most accurate projections from MISER (low, mid or high). Shown in Table 5.1-1 are the current and projected population trends based on MISER data for 2005 and 2010.

Table 5.1-1. Year 2000 and Projected Population Trends for Towns in the Millers River Basin

		Projected Population	
Town	Year 2000	Year 2005	Year 2010
Ashburnham	5,546	7,795	8,822
Athol	11,299	11,424	11,641
Erving	1,467	1,520	1,573
Gardner	20,770	22,133	23,272
Hubbardston	3,909	4,518	5,290
Montague	8,489	7,215	7,098
New Salem	929	957	982
Northfield	2,951	4,033	4,450
Orange	7,518	7,856	8,129
Petersham	1,180	1,323	1,401
Phillipston	1,621	2,410	2,856
Royalston	1,254	949	941

Town		Projected Population	
	Year 2000	Year 2005	Year 2010
Templeton	6,799	6,996	7,156
Warwick	750	849	896
Wendell	986	1,430	1,653
Westminster	6,907	7,058	7,539
Winchendon	9,611	10,316	11,054

5.2 Water Supply Forecast- Results

The only town where Method 1 could be applied was Athol. The remaining towns did not meet the criteria for Method 1's disaggregated water use forecast. The remaining towns had either very unreliable data containing anomalies in their water use, or they had higher than 15% UAW. To ensure quality assurance and quality control, Steve Asen of the Massachusetts Department of Environmental Management (MDEM) reviewed our estimates of future water supply demands as well as the selected method (1 or 2). Our analysis as well as background material (most notably the PWSASR for the past three years) were also supplied to Mr. Asen as background data for his review.

Table 5.2-1 shows the forecasted water needs for each community in the Millers River Basin for the years 2005, 2010 and 2020. The method used and 2001 average daily demand are also shown. Readers should note that for some towns, the forecasted water demand in 2005 might be lower than the water demand for 2001. This is due to using the average daily water demand for the last three years for the forecasting method. If 2001 water use was higher than the previous two years, this trend will occur.

Table 5.2-1: Forecasted Water Needs for Communities served by Public Water Suppliers in the Millers River Basin.

Water Supplier	Method Used	2001 Average Daily Demand (MGD)	Forecasted Water Supply Demand						Net Difference 2020-2001
			2005	Percent Increase Relative to 2001	2010	Percent Increase Relative to 2001	2020	Percent Increase Relative to 2001	
Ashburnham	2	0.25	0.30	19.1%	0.32	27.9%	0.36	44.6%	0.11
Athol	1	0.91	0.90	-0.8%	0.91	0.0%	0.95	3.7%	0.04
Gardner	2	1.98	2.15	8.4%	2.17	9.6%	2.21	11.8%	0.23
Orange	2	0.63	0.67	7.0%	0.69	9.4%	0.72	14.3%	0.09
Templeton	2	0.53	0.51	-4.4%	0.51	-2.7%	0.53	0.6%	0.00
Westminster	2	0.33	0.29	-12.4%	0.32	-3.0%	0.38	15.2%	0.05
Winchendon	2	0.65	0.93	42.3%	0.99	51.0%	1.10	68.4%	0.45
TOTAL		5.28	5.75	8.8%	5.91	11.9%	6.25	18.4%	0.97

5.3 Water Supply Forecasts- Analysis

The towns of Ashburnham and Winchendon showed the largest percent increase in water supply demands as early as the year 2005. Ironically, both towns utilize the same water supply source- Upper Naukeag Lake. It appears, based on the safe yield analysis, that this particular water supply source is fully tapped, which would result in a need to a) develop additional water supply sources, b) purchase water from another in-basin water department or c) import water from entities such as the MWRA. Gardner and Orange are also showing a steady increase in demand in 2005 (8.4% and 7.0%, respectively). The remaining water departments (Athol, Templeton, and Westminster) do not show any sizeable increase in demand over the 20-year planning horizon.

The net difference between basin wide demands in 2001 (5.28 MGD) relative to the projected demands in 2020 (6.25 MGD) is 0.97 MGD. The largest increases in the average daily demand between 2001 and 2020 were Winchendon, (0.45 MGD), followed by Gardner (0.23 MGD), and Ashburnham (0.11 MGD).   It should be noted that there is considerable amount of unaccounted for water (greater than 10%) for all of the water suppliers as illustrated earlier. In addition, three water suppliers do not have a water conservation plan in place. Instituting aggressive water conservation plans, in addition to limiting unaccounted-for-water, could help the water suppliers in terms of meeting future demands.

Shown in Figure 5.3-1 is a stacked bar chart showing the 2001 annual water usage for the four towns (Ashburnham, Gardner, Orange and Winchendon) showing a projected sizeable increase in demand over the 20 year planning horizon. Also shown is the projected water supply demand in 2005, 2010 and 2020.

5.4 Water Supply Forecasts- Summary

If, after aggressive water conservation measures are adopted and implemented, future demands outpace supply, water suppliers will have to evaluate other water supply sources. Before determining potential water supply sources, it will be important to understand when (approximate year), and what time of year (month) supplies are deficient. For example, the average annual demand may be attainable using current sources, but supplies during the summer may be inadequate to meet future peak demand. Assuming average annual demand exceeds the supply, alternative water supply sources will be required. The pros and cons (environmental, economic, regulatory, political) of developing other sources should also be examined.

A potential short list of water supply alternatives could include:

- Increasing withdrawals (surface or groundwater) at existing withdrawal locations (provided the safe yield is not already fully tapped),
- Creating new withdrawal locations within the Millers River basin,
- Importing water from outside the Millers River basin,
- Creation of new storage reservoirs to store the spring runoff, and augment summer demand by drafting water from storage,
- For existing water supply reservoirs, consider raising the dam elevation to create additional storage, provided that the safe yield of the basin is not already fully tapped,
- Developing small storage tanks for subdivisions to provide non-potable, outdoor water supply to offset summer demands,
- Develop man-made storage tanks for additional reserve.

For each of these and other potential water supply alternatives consideration should be given to:

- Regulatory hurdles, such as interbasin transfers which is regulated under the Massachusetts Interbasin Transfer Act,
- Water Management Act Requirements,
- Permitting,
- Hydrologic Evaluation (what is the safe yield of the system),
- Environmental Impacts (instream habitat, riparian habitat, wetlands, wildlife, etc) associated with new water withdrawals, creating water supply reservoirs, increasing storage capacity at existing reservoirs, or any other measure that would disturb the existing environment would require detailed analysis,
- Economics of Alternative Water Supplies (Engineering, Construction, etc),
- Community Input (potential opposition or support with developing additional water supplies),
- Political Landscape.

5.5 Water Supply Forecast- Recommendations

Water conservation plans are available for three of the six public suppliers. Water suppliers applying for a Water Management Act permit are required to submit a water conservation plan to the MDEP. A standard form for a Water Conservation Plan is required and has recently been updated (effective July 13, 2000). When the MDEP conducts its five-year review for the Millers River Basin, the new form will be transmitted to all public water suppliers in the basin that require a Water Management Act Permit. During the five-year review process, all permit conditions are reviewed including the water conservation plan. A review of the new water conservation plans for all six in-basin water suppliers is recommended.

6.0 National Pollutant Discharge Elimination System Dischargers

6.1 Background on NPDES

The National Pollutant Discharge Elimination System (NPDES) is one of the principal mechanisms for eliminating water pollution under the Federal Clean Water Act (CWA). It mandates that wastewater dischargers can discharge waste into surface waters only if a NPDES permit is obtained. In Massachusetts, the Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MDEP) jointly issue NPDES permits, which are typically renewed every four years. Dischargers are required to submit Discharge Monitoring Reports (DMR's) on a monthly basis to MDEP and EPA, which provide summary information such as:

- wastewater composition, including metals and other toxicants,
- for industries, their manufacturing process,
- point of discharge (river or tributary name),
- flow and frequency rates of discharge,
- period of discharge (seasonal or year-round), and;
- a point of contact.

EPA uses national effluent treatment and surface water quality standards to limit the type and amount of pollutants allowed in the discharge. Average monthly and maximum daily pollutant limits are expressed numerically, in mg/l or lbs/day. Tests of effluent toxicity on the survival, growth, and reproduction of aquatic organisms are also required.

As noted above, the permitee must regularly monitor the effluent and report the results to EPA and MDEP via the DMR's. Monitoring varies with facility size, pollutant type, and the river or stream. Penalties can be levied for violating permit conditions.

Discharge limits are based on the 7Q10 flow of the river. The 7Q10 is the lowest consecutive seven-day flow that statistically occurs once every ten years. Theoretically, the magnitude of the 7Q10 is sufficient to adequately dilute the permitted level of discharged pollutants into the river.

6.2 Millers River NPDES Dischargers

There are 12 NPDES discharges in the Millers River Basin as summarized in Table 6.2-1.

Table 6.2-1: NPDES Permit Dischargers in the Millers River Basin

Name	Type of Discharge	Permit No.	Receiving Water	Allowable Average[23] Monthly Discharge (MGD)
Winchendon Water Pollution Control Facility	Municipal Wastewater	MA0100862	Millers River	0.50 MGD (0.77 cfs)
Templeton Developmental Center	Sanitary Wastewater	MA0102156	Beaver Brook	0.05 MGD (0.08 cfs)

[23] Instantaneous discharges may exceed the limits below, which are based on an average monthly discharge.

Name	Type of Discharge	Permit No.	Receiving Water	Allowable Average[23] Monthly Discharge (MGD)
(Fernald School[24])				
Gardner Wastewater Treatment Plant	Municipal Wastewater	MA0100994	Otter River	5.00 MGD (7.73 cfs)
Athol Wastewater Treatment Plant	Municipal Wastewater	MA0100005	Millers River	1.75 MGD (2.71 cfs)
L.S. Starrett Company[25]	Planting Operating Wastewater & Cooling Water	MA0001350	Millers River	0.07 MGD (0.11 cfs)
Town of Royalston	Municipal Wastewater	MA0100161	Millers River	0.039 MGD (0.06 cfs)
Seaman Paper Company	Paper-Making Wastewater	MA0000469	Otter River	1.00 MGD (1.55 cfs)
Erving Center Wastewater Treatment Plant	Municipal Wastewater	MA0101052	Millers River	3.15 MGD (4.87 cfs)
Town of Erving (Village of Millers Falls), POTW#1	Municipal Wastewater	MA0101516	Millers River	1.02 MGD (1.58 cfs)
Erving POTW #3	Municipal Wastewater	MA0102776	Unnamed Brook	0.01 MGD (0.015 cfs)
Town of Orange	Municipal Wastewater	MA0101257	Millers River	1.10 MGD (1.70 cfs)
Town of Templeton	Municipal Wastewater	MA0100340	Otter River	2.80 MGD (4.33 cfs)

For each permitted facility in the Millers River Basin, the average daily discharge per month was obtained from the EPA's Permit Compliance System (PCS) database. The PCS contained discharge data back to the date of the most recent permit renewal. Data was then requested from the EPA back to 1993, and subsequently received through the Freedom of Information Act (FOIA).

The monthly treated discharge from each NPDES permit holder was obtained from the EPA for the period 1993-2001 (note that some dischargers had shorter periods of record) from which an average monthly discharge was computed. Shown in Figures 6.2-1 through 6.2-12 are the average monthly daily discharges from each facility for the specified period of record. Also, shown in Figure 6.2-13 are the NPDES discharge locations.

All of the dischargers met their average monthly discharge limit, except for the Winchendon Water Pollution Control Facility (WPCF), the Athol WWTP and the Orange WWTP. The Athol and Orange violations occur in April and/or March, which coincide with the spring freshet. Runoff from the Millers River Basin is typically high during this period, thus it is assumed that although the magnitude of discharge is in violation, proper dilution would likely occur.

[24] The Templeton Development Center (Fernald School) maintains its own water supply, but it withdraws less than 100,000 GPD, thus it was not evaluated in Section 4.0.

Alternatively, the Winchendon WPCF is in violation of the 0.50 MGD discharge limit for all months except July, August and September.

Wastewater treatment plants typically follow a daily cycle, where inflow to and outflow from the plant is highest in the morning and night. The discharge of treated effluent from the WWTP may follow a similar pattern as shown later in this document when evaluating hourly flow data at USGS gages (note that some WWTP's are located just upstream of USGS gages).

It should be noted that are two other water treatment plant dischargers that were not evaluated in this study including Gardner Water Treatment Facility (MAG640041) and the Ashburnham/Winchendon Joint Water Authority (MAG640045). The initial evaluation focused only on the WWTP discharges. As discussed in the recommendations, additional analysis of these water treatment plant discharges is warranted to provide a complete picture of flow releases to the basin.

6.3 Total NPDES Discharges in Otter and Millers Basin and Comparison to WMA Withdrawals

Similar to the water withdrawal evaluation, the average monthly discharge for each NPDES facility in the Otter and Millers River Basins was calculated (see Figures 6.3-1 and 6.3-2, respectively). For the Otter River Basin, the average monthly wastewater discharge varied from 6.5 cfs (September) to 10.5 cfs (April), averaging approximately 8 cfs annually. Similarly, in the Millers River Basin, the average monthly discharge varied from 13.5 cfs (September) to 21.5 cfs (April), averaging approximately 16 cfs annually.

The net difference between water withdrawals and return flow via the NPDES dischargers in the Otter River Basin, expressed as average monthly flows are illustrated in Figure 6.3-3. Keep in mind that the period of record for withdrawals and discharges vary slightly, but generally represent the period 1993-2000. As Figure 6.3-3 shows, there are periods in the spring when the NPDES discharges exceed the withdrawal volume. Alternatively, in the summer (July-September), withdrawals exceed the NPDES discharges. The same analysis was conducted on the Millers River Basin as shown in Figure 6.3-4. The same trends were also observed; NPDES discharges exceed the withdrawal in the spring, but are less than the withdrawal in the summer.

7.0 Determination of Stressed River Basins

In Sections 5.0 and 6.0 of this report, the quantity of water withdrawn and discharged to the Millers River Basin and subbasins was quantified on an average monthly basis for the approximate period of record 1993–2000. Thus, a hydrologic budget evaluation may be conducted to determine the net gain or loss of water from a given subbasin. This section uses the criteria set forth by the Massachusetts Water Resources Commission (WRC) to preliminarily identify whether a given subbasin is considered stressed. Background on the WRC's recent report entitled "Stressed Basins in Massachusetts" is provided below. Following a summary of the key points of the report is an analysis to determine whether subbasins in the Millers River basin are considered hydrologically stressed.

7.1 Massachusetts Water Resources Commission- Summary of a Stressed Basin

The 1999 work plan for the Massachusetts Water Resource Commission (WRC) called for an interagency committee to define a stressed river basin. In December 2001, the WRC issued a report, which included various methods to identify stressed river basins in Massachusetts. The purpose for developing methods to identify stressed basins was in response to the large amounts of time and money regulators and project proponents typically invest when trying to evaluate the potential environmental impacts of a project with limited background information on the natural resources of a site. The stressed basin classification system is intended to flag areas that may require a more comprehensive and detailed review of environmental impacts or require additional mitigation. General conclusions of the interagency committee include:

- A definition of stress includes streamflow quantity, quality and habitat factors (all three of these variables are described further below). To date, the state has conducted a preliminary investigation of stressed rivers based solely on water quantity, as streamflow data is readily available in computerized format.

- A lack of adequate quality, biological and hydrological data has necessitated the development of an interim method to define quantitative stress, which was applied at the major basin and major subbasin level. The state evaluated 72 USGS stream gages in Massachusetts and developed three statistics to quantify streamflow- median of annual 7-day low flow, median of annual 30-day low flow and median of low pulse duration. The statistical results were then used to determine a basin's stress level as either low, medium or high. At this juncture only the quantity of streamflow has been examined- water quality and habitat factors have not been examined. For example, habitat quality (riffles, runs, pools, substrate, cover, etc) has not been assessed on the rivers.

- A second method has been developed to determine quantitative stress for a tertiary or secondary subbasin, which can be easily applied on a site-specific basis, but has not been applied statewide as part of the classification developed under the interim (as described in the second bullet) method. The second method can be used by project proponents to determine whether smaller subbasins are hydrologically stressed.

- The second method should be used to refine basin stress classifications for tertiary or secondary subbasins wherever possible.

Interim Method to Delineate Hydrologically Stressed Basins

As noted above, the interim method to delineate hydrologic stress for river basins involves the comparison of low flow statistics for 72 stream gages in Massachusetts. The WRC report notes that for purposes of stressed basins, hydrologic stress is defined as the relative strength of rivers in Massachusetts. The WRC indicated that the numbers derived from this interim method are not useful outside of Massachusetts and are not based on habitat or water quality needs.

For each of the 72 stream gages three flow statistics were computed to quantify streamflow- as noted earlier they are: median of annual 7-day low flow (in cfs), median of annual 30-day low flow (in cfs) and median of low pulse duration (in days). The statistical results for all stream gages were then compared to each other by ranking the results. A determination was then made as to a rivers stress level- low, medium or high. The WRC report provided the stress levels for the Millers River and tributaries as shown in Table 7.1-1.

Table 7.1-1: Final Stress Classifications for the Millers River Basin USGS Gages (Source: WRC)

Station No.	Gage Name	Final Stress Level
01165000	East Branch Tully River near Athol	High
01163200	Otter River at Otter River	Medium
01162500	Priest Brook near Winchendon	High
01161500	Tarbell Brook near Winchendon	Medium
01162000	Millers River near Winchendon	Medium
01164000	Millers River at South Royalston	Medium
01166500	Millers River at Erving	Medium

Method to Determine if a Subbasin is Hydrologically Stressed

The WRC report provides steps to determine a subbasin's stress level (low, medium or high). Essentially a simple water budget analysis is conducted, where the amount of withdrawals and return flow is quantified and related to base flow in the river. The steps outlined in the WRC report are listed below. These steps were used to assess certain subbasins in the Millers River Basin where water withdrawals or return flow could be quantified.

1. Delineate the tertiary or secondary subbasin to be assessed. The USGS Streamstats Program (see below for further information on the program) was used to determine subbasin drainage areas.

2. Once the subbasin is delineated, water supply withdrawals should be located and quantified. All water supply withdrawal locations have been mapped. As discussed earlier, average monthly water supply withdrawals for WMA users were quantified for the approximate period 1993-2000.

3. Wastewater returns to the subbasin should also be located and quantified. Careful attention should be paid to determining which portions of a community discharge to the sub-basin via

a WWTP versus septic systems. The Mass-GIS does not have a readily available coverage of WWTP discharge locations, however, the latitude and longitude of each NPDES discharger was obtained from EPA reports and plotted on the Millers River Basin map. Again, all NPDES dischargers in the basin were identified and return flow data was analyzed on an average monthly basis for the approximate period 1993-2001.

4. The total subbasin withdrawals, wastewater treatment plant returns and septic returns should be summarized as well as the resulting net inflow or outflow of water from the subbasin. It should be noted that this analysis did not include septic system returns, as these data were not readily available.

5. Determine the estimated natural 7Q10 and August median flows for the subbasin. These natural flow statistics can be estimated using the Streamstats program from the USGS at http://ma.water.usgs.gov/streamstats. The Streamstats program calculates natural flow conditions at any point in a river or tributary. The USGS has developed equations used to estimate various low-flow streamflow statistics for locations on Massachusetts's streams. The equations were derived from regression analysis, which statistically relates the streamflow statistics for a group of USGS stations to physical characteristics (total length of stream, area of surficial stratified drift, mean basin slope, and hydrologic region) of the drainage basins for the stations. Output from the program consists of the following streamflow statistics: 7Q2, 7Q10, 99-, 98-, 97-, 95-, 75- and 50% annual exceedence flows, and the August median flow. The program also calculates prediction intervals at the 90% confidence level streamflow. It should be noted that the program does not generate average daily flow data, only low-flow statistics are provided.

The WRC developed the criteria in Table 7.1-2 to determine a streams stress classification (low, medium, or high).

Table 7.1-2. Massachusetts Stream Classification Criteria

Stress Classification	Criteria
High	Net outflow equals or exceeds estimated natural August median flow
Medium	Net outflow equals or exceeds estimated natural 7Q10 flow
Low	No net loss to the sub-basin

7.2 Application of WRC Method to determine Hydrologically Stressed Subbasins in the Millers River Basin

Using the steps outlined in Section 7.1, an assessment of subbasin stress in the Millers River Basin was conducted. The MDEM was consulted on whether smaller or larger subbasins should be evaluated to determine stress level. In the case of the Otter River Basin there are numerous withdrawal locations and return flows. Instead of evaluating each individual subbasin where a water withdrawal occurs, the Otter River was examined as a whole. Evaluating individual subbasins will most likely result in either a medium or high stress classification, since the magnitude of withdrawal relative to the subbasin area is typically high. In addition, smaller subbasins do not contain return flow from WWTP's as these facilities typically discharge to larger rivers such as the Otter River or Millers River. It should also be noted that by evaluating larger watersheds, the impact of withdrawals might be lessened. For example, the Tully River basin contains three wells (Athol Water Division) that withdraw water just upstream of the confluence with the Millers River. The Tully River drainage area at the confluence with the Millers River is 72.8 mi^2 and thus the magnitude of withdrawal relative to the drainage area is small—hence the stress level is low.

For purposes of this study, we examined primarily larger subbasins, and several smaller subbasins that were direct tributaries to the Millers River (e.g. North Pond Brook which has a water supply withdrawal). It should be reiterated that the evaluation of stress was based solely on a few low flow statistics and did not consider many other factors that play a role in river stress such as dam operations, water quality or instream habitat. For example, the stress level in a particular river reach may be considered low using the classification system, however, dam operations may result in a pulsing discharge where flows fluctuate over 50 cfs in a day, or water quality is considered poor. These factors would likely change the stress level to medium or high.

Shown in Table 7.2-1 are the subbasins that were examined as part of this study as well as the water withdrawal points and return flows within each subbasin. It should be noted that water withdrawal and wastewater discharges are shown for each basin as a whole.

Table 7.2-1: Subbasins in the Millers River Basin used to calculate or estimate stress level (also shown is the Water Withdrawal and Return flows, and the corresponding period of record).

Subbasin Name	Water Withdrawal	Period of Record Used in the Analysis	Wastewater[26] Discharge	Period of Record Used in the Analysis
Otter River	Gardner Dept Pub Works	1/1993-12/2000	Gardner WWTP	1/1993-11/2001
	Templeton Water Dept.	1/1993-12/2000	Town of Templeton	1/1993-11/2001
	Seaman Paper	1/1993-12/1999	Seaman Paper Co.	1/1993-11/2001
	American Tissue	1/1994-12/1995		
Upper Naukeag Lake	Ashburnham Water Dept.	1/1993-12/2000		
	Winchendon Water Dept.	1/1993-12/2000		
Tully River	Athol Dept of Pub Works	1/1995-12/2000		
North Pond Brook	Orange Water Dept (Wells 1 and 2)	1/1993-12/2000		
Unnamed Tributary to Millers River	Orange Water Dept (Well 3)	1/1993-12/2000		
Millers River (includes all withdrawals greater than 0.1 MGD and all NPDES discharges)	Gardner Dept Pub Works	1/1993-12/2000	Gardner WWTP	1/1993-11/2001
	Templeton Water Dept.	1/1993-12/2000	Town of Templeton	1/1993-11/2001
	Seaman Paper	1/1993-12/1999	Seaman Paper Co.	1/1993-11/2001
	American Tissue	1/1994-12/2000	Town of Orange	1/1993-11/2001
	Ashburnham Water Dept.	1/1993-12/2000	Winchendon WPCF	1/1993-11/2001
	Winchendon Water Dept.	1/1993-12/2000	Templeton Developmental Center	1/2000-7/2001
	Athol Dept of Public Works	1/1995-12/2000	Athol WWTP	1/1993-11/2001
	Orange Water Dept	1/1993-12/2000	L.S. Starrett Co.	1/1993-11/2001
	Erving Paper	1/1993-12/2000	Town of Royalston	10/1999-7/2001
	International Paper	1/1993-12/2000	Erving Center WWTP	1/1993-11/2001
			Town of Erving, POTW#1	1/1993-11/2001

[26] The WWTP discharges are listed by subbasin and are not necessary tied directly to the water withdrawal location shown in Column 2.

Subbasin Name	Water Withdrawal	Period of Record Used in the Analysis	Wastewater[26] Discharge	Period of Record Used in the Analysis
			Erving POTW #3	2/1996-10/2001

Background on Approach and Analysis

Using the Mass-GIS basin map of the Millers River, the following overlays were added as shown in Figure 7.2-1: water withdrawal locations, and NPDES return flow locations. Subbasins selected for the stress evaluation were determined by the location of water withdrawals. For example, Orange Water Department has two wells located in the North Pond Brook subbasin. In the case of groundwater wells, no evaluation was conducted to determine if the zone of withdrawal overlapped into an adjacent subbasin, rather it was assumed that the entire withdrawal occurred within the delineated subbasin.

The average monthly water withdrawals and return flows for each water supplier and discharger were computed for the periods of record shown in Table 7.2-1. For those subbasins where there were multiple water withdrawals or return flows, total withdrawals and return flows were summed for each month. Total monthly return flows were then subtracted from the total monthly water withdrawal to yield the net water gain (+) or loss (-) from the given subbasin (see Table 7.2-2 (end of this section) Net Gain or Loss of Flow from Subbasins in the Millers River Basin).

In addition, the USGS Streamstats program was used to delineate the subbasin drainage area, and to estimate the natural 7Q10 and August median flows. Using the classification system in Table 7.2-2, the subbasins stress level was classified as low, medium or high by comparing the net water loss or gain relative to the 7Q10 and August median flow. It should be noted that some subbasins contained only water withdrawals and no return flow, thus there was always a net loss of water.

The computed loss or gain in water from each subbasin was then compared to the 7Q10 and August median flow (from Streamstats) to determine the stress level. The figure numbers and stress level determination for each subbasin are summarized in Table 7.2-3.

Table 7.2-3: Stress Level Summary for Subbasins in the Millers River Basin as determined according to the Water Resource Commission procedures

Subbasin Name	Drainage Area[a] (mi^2)	7Q10 Flow[a] (cfs)	August Median Flow[a] (cfs)	WRC method-Stress Classification	Figure No.
Otter River	60.54 mi^2	1.91 cfs	11.6 cfs	Medium	7.2-2
Upper Naukeag Lake	1.90 mi^2	0.04 cfs	0.29 cfs	High	7.2-3
Tully River	72.80 mi^2	4.01 cfs	17.63 cfs	Low	7.2-4
North Pond Brook	1.98 mi^2	0.08 cfs	0.51 cfs	Medium	7.2-5
Millers River	388.87 mi^2	23.68 cfs	98.20 cfs	Low	7.2-6

[a] The drainage area, 7Q10, and August Median Flow were computed by the USGS Streamstats Program.

TABLE 7.2-2 Net Gain or Loss in Flow from Subbasins in the Millers River Watershed

Basin		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	
Otter River Basin	Withdrawals	9.25	9.09	9.21	9.2	9.3	9.27	8.61	9.49	10.1	8.3	8.08	8.03	8.99	
	Returns	8.26	7.77	9.81	10.5	8.51	7.81	6.76	6.54	6.47	6.96	7.07	7.97	7.87	
	Return-Withdrawal	-0.99	-1.32	0.6	1.31	-0.79	-1.46	-1.84	-2.94	-3.67	-1.33	-1.01	-0.06	-1.12	
	7Q10 Flow	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	Medium Stress
	August Median Flow	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	
Upper Naukeag Lake	Withdrawals	1.82	1.94	1.84	1.85	2.02	2.11	2.26	2.19	2.01	1.89	1.81	1.8	1.96	
	Returns	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Return-Withdrawal	-1.82	-1.94	-1.84	-1.85	-2.02	-2.11	-2.26	-2.19	-2.01	-1.89	-1.81	-1.8	-1.96	
	7Q10 Flow	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	High Stress
	August Median Flow	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	
North Pond Brook	Withdrawals	0.25	0.24	0.25	0.24	0.22	0.24	0.21	0.27	0.25	0.23	0.24	0.26	0.24	
	Returns	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Return-Withdrawal	-0.25	-0.24	-0.25	-0.24	-0.22	-0.24	-0.21	-0.27	-0.25	-0.23	-0.24	-0.26	-0.24	
	7Q10 Flow	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	Medium Stress
	August Median Flow	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	
Unnamed Tributary	Withdrawals	0.72	0.8	0.79	0.73	0.8	0.85	0.85	0.76	0.73	0.68	0.7	0.69	0.76	
	Returns	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Return-Withdrawal	-0.72	-0.8	-0.79	-0.73	-0.8	-0.85	-0.85	-0.76	-0.73	-0.68	-0.7	-0.69	-0.76	
	7Q10 Flow	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	
	August Median Flow	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	High Stress
Tully River	Withdrawals	1.38	1.38	1.31	1.33	1.46	1.61	1.54	1.53	1.42	1.31	1.27	1.27	1.4	
	Returns	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Return-Withdrawal	-1.38	-1.38	-1.31	-1.33	-1.46	-1.61	-1.54	-1.53	-1.42	-1.31	-1.27	-1.27	-1.4	
	7Q10 Flow	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	Low Stress
	August Median Flow	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	
Millers River	Withdrawals	19.7	19.9	19.9	20	20.5	20.6	20	20.7	20.9	18.8	18.4	18.1	19.8	
	Returns	16.8	16.2	20.1	21.5	17.3	15.9	14.1	13.7	13.5	14.6	14.9	16.3	16.3	
	Return-Withdrawal	-2.89	-3.67	0.16	1.49	-3.19	-4.73	-5.85	-6.96	-7.42	-4.23	-3.51	-1.83	-3.55	
	7Q10 Flow	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	Low Stress
	August Median Flow	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	

All flows are in cfs.

8.0 Hydrologic Evaluation of USGS and Other Gage Data

In this section existing flow records for the Millers River Basin were analyzed and evaluated using conventional methods as well as using the Nature Conservancy's Indicators of Hydrologic Alteration (IHA).

8.1 Existing Flow Database

The United States Geological Survey (USGS) maintains various stream gages in the Millers River Basin, some that are active and others that are retired. In addition, some gages do not record flow on a continuous basis, rather they are considered low flow or peak flow gages. Shown in Figure 8.1-1 are the continuous recording USGS gages and Corps gages located in the Millers River Basin (data was obtained by Mass-GIS). In addition, shown in Table 8.1-1 is a summary of the USGS gages in the basin along with information on the location, drainage area, period of record and upstream sources of regulation.

Table 8.1-1: USGS and Corps Flow Gages Located in the Millers River Basin (Active and Retired)

Station Name	Drainage Area (mi^2)	Period of Record	Sources of Regulation
USGS Gages			
Tarbell Brook near Winchendon, MA	17.8	6/1/1916-9/6/1983	No Information
Millers River near Winchendon, MA	81.8	6/5/1916-current	Flow regulated by Lake Monomonac, and other reservoirs, and prior to 1957 by powerplants
Priest Brook near Winchendon, MA	19.4	6/1/1916-current	Prior to 1962, occasional diurnal fluctuation at low flow by mill upstream, prior to 1953 regulation at low flow by mill and ponds
Otter River at Gardner Rd, MA	20.0	7/1/1916-9/30/1917	No Information
Otter River at Otter River, MA	34.1	12/1/1964-9/30/1997 10/1/1998-9/30/1999	No regulation described.
Millers River at South Royalston, MA	189.0	8/1/1939-10/31/1990	Flow regulated by Lake Monomonac and other reservoirs, by mills and powerplants prior to 1955, and at high flow by Birch Hill Reservoir since 1941
East Branch Tully River Near Athol, MA	50.5	6/13/1916-12/5/1990	Flow regulated by Tully Reservoir since 1948.
Lake Rohunta Outlet near Athol, MA	20.3	12/1/1964-10/30/1985	Flow regulated by Lake Rohunta
Moss Brook at Wendell Depot, MA	12.1	6/1/1916-9/30/1982	No Information
Whetstone Brook at Wendell Depot, MA	5.22	12/18/1985-9/30/1991	No Information
Millers River at Erving, MA	372.0	7/1/1915-current	Flow regulated by powerplants and by Lake Monomonac and other reservoirs; high flow regulated by Birch Hill and Tully Reservoir; greater regulation by powerplants prior to 1966.

Corps Data			
Millers River near Athol, MA	280.0	current	Flow regulated by powerplants and by Lake Monomonac and other reservoirs; high flow regulated by Birch Hill and Tully Reservoir; greater regulation by powerplants prior to 1966.
Outlet of Tully Dam (Note lake elev. data is available)	50.0	Flow data available from USGS Gage on East Branch Tully River	Flow regulated by Tully Dam since 1948
Outlet of Birch Hill Dam (Note: lake elev. data is available)	175.0	Flow data available from USGS gage on Millers River at South Royalston	Flow regulated by Birch Hill Dam since 1941

In addition to the USGS gage stations the Corps was contacted to determine what information they record at the Birch and Tully Lake Flood Control Projects. Per conversations with Carmen Suarez of the Corps, hourly elevation and discharge data is available in electronic format for both projects, although the period of available record varies. The Birch Hill discharge data is actually recorded at the USGS gaging station in South Royalston. Publication of the South Royalston gage flow data was discontinued in 1990; however, the Corps still uses the gage. The drainage area at Birch Hill Dam and the South Royalston gage are 175 and 189 mi^2, respectively, thus there is an additional 14 mi^2 of drainage between the dam and gage.

In addition to the lake level data, the Corps has a flow gaging station on the Millers River in Athol, located just downstream of the Tully River confluence. There has been some speculation that this particular gage is subject to backwater effects from the New Home Dam and thus may not represent a true flow reading. In addition, the gage has not been rated since 1990, and maintenance on the gage is performed only on an as-needed basis. No measurements to update or verify the rating curve have been taken or are planned in the future. In our analysis below we only evaluated the hourly flow data at the Corps gage for 2000.

8.2 Critical Components of the Flow Regime and Potential Effects on Aquatic Resources

One of the goals of this project is to determine the impact of regulation on ecological processes. River ecology is directly linked with flow conditions in the basin. Five critical components of the flow regime regulate ecological processes in river ecosystems: the magnitude, frequency, duration, timing and rate of change of hydrologic conditions (Poff and Ward, 1989, Richter et al. 1996, Walker et al. 1995). These components can be used to characterize the entire range of flows and specific hydrologic phenomena, such as floods or low flows, which are critical to the integrity of river ecosystems. A description of each hydrologic variable is explained below.

- The *magnitude* of discharge at any given time interval is the amount of water moving by a fixed location per unit time. The magnitude of flow has an effect on available river habitat- as wetted area shrinks typically aquatic habitat also shrinks.

- The *frequency* of occurrence refers to how often a flow above a given magnitude recurs over some specified time interval. Frequency of occurrence is inversely related to flow magnitude. For example, a 100-year flood is expected to be equaled or exceeded once every 100 years. Extreme events such as droughts or floods may be tied to reproduction or mortality events for various species, thereby influencing population dynamics.

- The *duration* is the period of time associated with a specific flow condition. For example a flow duration curve might provide information on the percent of time or number of days in a year a specific flow is equaled or exceeded. The duration of flow may determine whether a particular life-cycle phase can be completed or the degree to which stressful effects such as inundation or desiccation can occur.

- The *timing* of flows of defined magnitude refers to the regularity with which they occur. Timing of flows can determine whether certain life-cycle requirements are met or can influence the degree of stress or mortality associated with extreme water conditions such as drought or floods.

- The *rate of change* or flashiness refers to how quickly flow changes from one magnitude to another. The rate of change in flow may cause stranding of certain organisms along the river's edge or in ponded depressions or sudden inundation.

In the following sections of this report, we use various tools to determine how the five hydrologic variables described above might be impacted by human activities on the Millers River Basin.

8.3 Evaluation of Virgin or Unregulated Flow Conditions

One of the goals of this project was to identity and describe natural/biological resources that might be affected by current and potential modifications in the hydrology of the Millers River Basin relative to "virgin flow" conditions. Various terms are used to describe virgin flow conditions such as "Pilgrim flow", "Natural flow" or "Unregulated flow", although defining virgin flow conditions is extremely difficult. Presumably virgin flow conditions would represent conditions where there has been no alteration in the magnitude, timing, frequency, rate of change or duration of flow caused by human disturbances, nor any change in the basin's land use (such as logging or development- also caused by humans). It is nearly impossible to predict flow conditions before any human activities occurred in the Millers River Basin. USGS flow records date to the early 1900's, well after human alteration of the flow regime and land use changes occurred in the basin. For purposes of this report, the term unregulated flow was used in lieu of virgin flow. Unregulated flow is representative of no human manipulation of flow, but land use conditions representative of existing conditions. Some human activities that could affect flow include:

- Construction of dams and hydropower projects that change the natural hydrograph. Hydropower projects can operate as daily peaking plants, resulting in the pulsing of discharges below the facility. Also, seasonally operated reservoirs that utilize storage to reduce peak flood flows also change the unregulated flow regime by shifting the seasonal distribution of flow.

- Water withdrawals for water supply or industrial needs can affect the magnitude and timing of flow in river reaches located below the withdrawal point.
- Discharges from wastewater treatment plants (WWTP) can also affect the magnitude, timing and rate of change of flow below the discharge point. As described later, WWTP's follow the general pattern of water usage throughout the day, where peak use occurs in the morning and night.
- Changes in land use have occurred over time in the Millers River Basin. The extent of development in the basin is considered low relative to other basins in Massachusetts. As noted earlier over 81% of the Massachusetts portion of the watershed is considered forested, thus large-scale development is limited. Land use changes that change flow patterns include: a) development in wetland areas can alter the runoff by reducing the natural buffering capacity of the river b) increased urbanization can result in larger impervious surfaces, which changes the timing and magnitude of runoff, c) other activities such as logging or timber harvesting can affect runoff and d) stormwater drainage systems.

To quantify the affects of human activities, hydrologists typically rely on long-term flow records to conduct pre and post impact hydrologic analysis. To determine if there was any period of record in which the flow regime was representative of unregulated conditions, shown in Figure 8.3-1 is a timeline of dam construction in the Millers River Basin relative to the available USGS flow record. As Figure 8.3-1 shows, dams were constructed on the Millers River in the early 1900's as part of the Industrial Revolution, some before any flow records were available[27]. In addition to dam construction, there were presumably water withdrawals occurring within the basin as well. It is unknown when each of the public water suppliers or industrial withdrawals began operation. However, to provide a sense of the potential water use demand, population estimates from 1900 to 2000 are shown in Figure 8.3-2 for Worcester County. Most of the Millers River Basin is located within Worcester County, and thus the population estimates can provide a rough approximation of population growth and water demand. As Figure 8.3-2 shows, since 1900 the population has more than doubled in Worcester County. Therefore, it is likely that municipal water supply services began delivering water during this time frame, which also impacts streamflow. Because dam construction and water supply withdrawals have occurred since flow records were maintained, it is not possible to estimate true unregulated flow conditions in the Millers River Basin by using existing USGS gage records.

Another method for estimating unregulated flows is the USGS Streamstats Program. The USGS has developed 13 equations that can be used to estimate various low-flow streamflow statistics for locations on Massachusetts's streams. The equations were derived from regression analysis, which statistically relates the streamflow statistics for a group of USGS stations to physical characteristics (total length of stream, area of surficial stratified drift, mean basin slope, and hydrologic region) of the drainage basins for the stations. One of the equations can be used to estimate the 7-day, 10-year low flow (7Q10) -- a statistic used by the U.S. Environmental Protection Agency (EPA) and State agencies for permitting of pollutant (NPDES) discharges. Another equation estimates the August median flow, which is used by the U.S. Fish and Wildlife Service (USFWS) in New England as the minimum flow needed to protect aquatic animals and

[27] It should be noted that there are many other dams in the basin not listed in the table that were likely constructed in the late 1800's and early 1900's.

plants. At present, Streamstats only provides low-flow statistics, but work is underway to incorporate flood statistics as well.

Output from the Streamstats program consists of the following statistics:

- 99, 98, 95, 90, 85, 80, 75, 70, 60 and 50% Annual Exceedence Flows,
- 7 day, 2 year low flow (7Q2) and 7 day, 10-year low flow (7Q10)[28], and,
- August median flow (50% Exceedence Flow)[29]

The program also calculates prediction intervals at the 90% confidence level streamflow. It should be noted that the program does not generate average daily flow data; only low-flow statistics are provided. Thus, daily time step hydrographs or flow duration curves cannot be developed. In addition, exceedence flows provided in the program outputs are based on annual flow statistics, not monthly flow statistics. Thus, the seasonal regulation of flow, which occurs at the Corps facilities, will not be depicted in the output.

The USGS also notes that there are limitations to using the Streamstats program. They recognize that the program may be used to calculate streamflow statistics at an existing USGS gage site to determine the difference in regulated and unregulated flow conditions. They warn users not to assume that the difference between the two sets of estimates (regulated and unregulated) are equivalent to the effects of human activities on streamflow at the station because there are errors associated with both sets of estimates.

For this study, the Streamstats program was used to estimate low flow statistics (for unregulated flow) at each of the existing USGS gages. Comparisons of low flow statistics for unregulated and regulated flow conditions were summarized in Table 8.3-1. Bar graphs were developed for each USGS gage displaying the annual exceedence flows, 7Q2, 7Q10 and August median flow under current (regulated) and unregulated (computed using Streamstats) flow conditions. Also shown on the graphs is the percent difference in the flow statistic relative to unregulated conditions. Graphs for the following gages were developed and are attached to the end of this section:

Figure 8.3-3 Tarbell Brook near Winchendon, MA (Drainage Area= 17.8 sq mi)
Figure 8.3-4 Millers River near Winchendon, MA (Drainage Area= 81.8 sq mi
Figure 8.3-5 Priest Brook near Winchendon, MA (Drainage Area= 19.4 sq mi
Figure 8.3-6 Otter River at Otter River, MA (Drainage Area= 34.1 sq mi)
Figure 8.3-7 Millers River at South Royalston, MA (Drainage Area= 189 sq mi)
Figure 8.3-8 East Br. Tully River near Athol, MA (Drainage Area= 50.5 sq mi)
Figure 8.3-9 Lake Rohunta Outlet near Athol, MA (Drainage Area= 20.3 sq mi)

[28] Streamstats uses the Log-Pearson Type III distribution for computing low flow frequency statistics. The same method was used to compute regulated low flow frequency statistics shown in Table 8.3-1.
[29] Streamstats computes the August median flow as the median of the daily mean flows for all complete Augusts during the period of record. The same method was used to compute the regulated August median flow. Alternatively, the USFWS recommends calculating the August median flow as the median of the annual series of August monthly mean flows during the period of record. The USFWS uses the August median flow as the minimum flow required for summertime maintenance of habitat for biota in New England streams.

Figure 8.3-10 Moss Brook at Wendell Depot, MA (Drainage Area= 12.1 sq mi)
Figure 8.3-11 Whetstone Brook at Wendell Depot, MA (Drainage Area= 5.22 sq mi)
Figure 8.3-12 Millers River at Erving, MA (Drainage Area= 372 sq mi)

Some interesting observations can be gleaned from these figures.

All regulated flow statistics (95%, 90%, 85%, 80%, 75%, 70%, 60%, 50%, 7Q2, 7Q10 and August median flow) for the following gages exceeded the unregulated flow statistics: Whetstone Brook, Millers River near Winchendon, Otter River, and Millers River at South Royalston. Tarbell Brook was similar having only two unregulated flow statistics (60% and 50% exceedence flows) that were greater than the regulated flow. For the five remaining gages, some unregulated flow statistics were greater than the regulated flow condition.

It is interesting to note that the unregulated August median flow was greater than the regulated condition for only 2 of the 9 USGS gages evaluated- they are the Millers River at Erving[30], and Moss Brook (Priest Brook difference is minor). It should be noted that the output from the Streamstats program does not assign a period of record used in the analysis. Thus, it is uncertain if comparisons between regulated and unregulated flow conditions are based on similar periods of record. A shorter period of record could skew the results. The USFWS recommends a minimum of 25 years of record when computing the August median flow and other flow statistics (USFWS, New England Regional Flow Policy).

One hypothesis for the higher regulated August median flow is that reservoir storage within the Millers River Basin is being used to supplement natural flows during the summer perhaps for hydropower generation or other needs. The largest source of reservoir storage is contained within the Birch Hill and Tully Lake Corps facilities. However, as illustrated later in this report during the summer period, both of these reservoirs are operated close to a stable pond elevation. The amount of reservoir storage capacity in the Millers River Basin, aside from the Corp facilities, is also relatively minor. Also, based on conversations with various dam owners, most projects are operated at a relatively stable reservoir level during the summer. In addition, many of the USGS gages are located upstream of the Corps storage projects. In summary, it is unclear why the regulated August median flow is consistently higher than the unregulated flow.

With respect to the 7Q10 flow, only 3 of the 9 USGS gages show a higher unregulated 7Q10 flow than the regulated 7Q10- they are East Branch Tully River, Priest Brook and Lake Rohunta outlet. Again, it is difficult to pinpoint why the unregulated 7Q10 flow is not consistently higher or lower than the regulated 7Q10 given the number of uncertainties including: a) the period of record used by Streamstats to compute the unregulated 7Q10 flow, b) the uncertainty in the predicted 7Q10 from Streamstats.

[30] It should be noted that two periods of record were used to quantify regulated flow conditions on the Millers River at Erving and East Branch of the Tully River. The graphs contained in this section use the period of record after the Corps facilities were constructed, thus reflecting a higher level of regulation.

8.4 Evaluation of USGS Gage Records

In Section 8.3, low flow statistics were compared between regulated and unregulated flow conditions. Interestingly, the regulated flow statistics were generally higher than the unregulated flow statistics developed using Streamstats. Although, the USGS gage records all reflect some level of regulation, the period of record for most gages is well in excess of 50 years. Given the long period of record, and given the later construction of Birch Hill (1941) and Tully Lake (1949) flood control facilities, some general trends in long-term flow statistics might be identified. Thus, in this section we examine the magnitude, duration, frequency and rate of change of the USGS gages in the Millers River Basin.

Period of Record for Analysis

The period of record used to examine flow conditions varied for each gage. Ideally, identifying an exact human activity that would cause an impact on streamflow is desirable such that pre and post changes can be quantified and compared. In the Millers River Basin there are numerous dams that were constructed in the early 1900's, which likely affected the natural flow pattern. Operation of the two Corps flood control facilities likely causes the largest change in flow patterns in the river reaches below the projects, thus we have evaluated two different periods of record for those gages affected by the Corps projects- a pre/post dam construction period evaluation was conducted. There are two USGS gages that are affected by the Birch Hill and Tully Lake Flood Control projects: East Branch Tully River (Tully Lake), and Millers River at Erving (Birch Hill and Tully Lake). The Millers River at South Royalston gage is located below Birch Hill Dam, but the gage was operational just a couple of years before the dam was constructed. Because the pre-dam flow record at the South Royalston gage was limited, no pre/post impact analysis was conducted. It is understood that human activities have caused changes in flow patterns before, as well as after the Corps facilities were constructed. Therefore, any changes in the flow regime may not be the sole result of the Corps facilities.

For the remaining USGS gages, there was no distinguishable pre/post impact period as human activities have been occurring over time. 1950 was selected as an arbitrary break point since it is the approximate mid-point for the gage records. It was also assumed that water withdrawals during pre-1950 would be less than the post-1950 period.

8.4.1 7-Day Consecutive Low Flow and Low Flow Frequency Analysis (7Q10)

For each of the USGS gages, the 7-day consecutive low flow was computed for each calendar year and then plotted on a bar graph to identify any trends (see Figure 8.4.1-1 to 8.4.1-9). Also shown on the plots is the pre/post 1950 7Q10 flow as well as the pre/post Corp Dam 7Q10 flow (again, this only applies to the Millers River at Erving and East Branch of the Tully River gages). Lastly, the distribution of when the 7-day low flow occurs is shown. As expected, the majority of low flow events occur between July and October, with September having the highest overall percentage.

The 7-day low flow is of critical importance for biological and water quality purposes. As noted earlier, WWTP's are typically designed such that adequate dilution occurs at the 7Q10 flow. A reduction in the 7Q10 flow could create water quality and public health/safety concerns in the river reach below a WWTP outfall. From a biological standpoint, severe droughts or extended periods of low flow can limit aquatic reproduction and can cause mortality events, which influence population dynamics. Thus, when reviewing the bar charts for the various gages, any evident trends in the 7-day low flow were identified. It should also be noted that in the early 1960's there was a drought in the northeast, which resulted in some of the lowest 7-day consecutive low flows on record. Thus, when comparing 7Q10 flows (before and after roughly 1950), keep in mind that the 1960's drought will likely lower the 7Q10 flows somewhat. The following figures were developed.

8.4.1-1 Tarbell Brook near Winchendon, MA
8.4.1-2 Millers River near Winchendon, MA
8.4.1-3 Priest Brook near Winchendon, MA
8.4.1-4 Otter River at Otter River, MA
8.4.1-5 Millers River at South Royalston, MA
8.4.1-6 East Branch Tully River near Athol, MA
8.4.1-7 Lake Rohunta Outlet near Athol, MA
8.4.1-8 Moss Brook at Wendell Depot, MA
8.4.1-9 Millers River at Erving, MA

Based on the above figures, there were no specific patterns in the 7Q10 flow over time, except for the East Branch of the Tully River. The Tully Lake Flood Control Facility was constructed in 1949. The 7Q10 flow was computed for the following periods of record: 1917-1947: 2.03 cfs, and 1950-1989: 0.53 cfs. The post dam 7Q10 flow was considerably lower (by roughly 74%) than the pre dam period (again the post dam period included the 1960's drought). Potential causes of the lower post dam 7-day low flows include the operation of Tully Dam discharges, the loss of water due to lake evaporation or changes in the hydrologic record.

It is interesting to note that the Millers River at Erving gage, located below both Corps facilities, did not show a sizeable difference between the pre and post dam 7Q10 flow (1916-1940- 49.4 cfs, 1950-1998- 45.9 cfs). For the remaining gages, the pre and post 1950 7Q10 flows did not vary considerably and no patterns were observed in the bar charts.

8.4.2 Instantaneous Peak Flows and Flood-Frequency Analysis

As noted earlier, the ability to store large flood flows in storage reservoirs in the Millers River Basin is limited to the Tully Lake and Birch Hill Dam Flood Control Facilities. Other reservoirs in the basin have limited storage capacity and are not expected to significantly change the magnitude or timing of the peak flow relative to an unregulated condition. For each of the USGS gages, the annual instantaneous peak flow was identified for each calendar year and then plotted on a bar graph to identify any trends (figures are listed below). Although the instantaneous peak flows were plotted for each gage, the main focus is on the two gages that are influenced by the two flood control projects- the Millers River at Erving and the East Branch Tully River. Again, the remaining USGS gages did not reflect any trends in the magnitude of peak flows over time due to the lack of storage in these basins.

For the Millers River at Erving and East Branch Tully River gages, pre/post dam construction flood frequency analysis (based on annual instantaneous peak flow data) were conducted for the following return intervals: 10-, 20-, 50- and 100-year flood frequency. Lastly, the distribution of when the instantaneous peak flow occurred is shown on the figures. As expected, the majority of peak flow events occur during March and April (due to precipitation on a ripe snowpack). The two largest floods on record in the Millers River Basin include the March 1936 and September 1938 storms. The March/April 1987 flood event was contained due to the Corps facilities. The following figures were developed:

8.4.2-1 Tarbell Brook near Winchendon, MA
8.4.2-2 Millers River near Winchendon, MA
8.4.2-3 Priest Brook near Winchendon, MA
8.4.2-4 Otter River at Otter River, MA
8.4.2-5 Millers River at South Royalston, MA
8.4.2-6 East Branch Tully River near Athol, MA
8.4.2-7 East Branch Tully River near Athol, MA- Flood Frequency Results
8.4.2-8 Lake Rohunta Outlet near Athol, MA
8.4.2-9 Moss Brook at Wendell Depot, MA
8.4.2-10 Millers River at Erving, MA
8.4.2-11 Millers River at Erving, MA- Flood Frequency Results

As noted above, there is no clear trend in peak flows at the gages unaffected by the Corps projects. As shown in Figure 8.4.2-7, the flood-frequency analysis for the East Branch of the Tully River shows much lower flows since the Tully Dam was created. It should be noted, however, that the floods of 1936 and 1938 were the largest on record, and thus can skew the results. Floods of this magnitude have not been observed in the Millers River basin since the construction of the flood control facilities. Similar trends and findings were observed for the Millers River at Erving flood-frequency; post Birch Hill and Tully Dams has reduced flood peaks as shown in Figures 8.4.2-10 and 8.4.2-11.

Undoubtedly, the Corps facilities were constructed to protect communities such as Athol and Orange from suffering severe flood damages, as occurred in 1936 and 1938. However, flood flows naturally occur and do serve a biological function. Floods cause strong annual interaction between the river and its floodplains and wetlands. The natural riverine ecosystems depend on these interactions for maintenance. These patterns in many cases provide triggers to biological organisms through various stages of their lifecycles. Increasingly, instream flow requirements also include provisions for *flushing flows* or *channel maintenance flows*, deliberate high flow releases designed to mimic the effects of natural floods, to remove fine sediment accumulated on the bed (especially in spawning gravels) and in an attempt to maintain pre-dam channel form. Removal of fine sediments from gravel beds results in more ideal spawning substrates.

8.4.3 Distribution of Mean Monthly Flow and Annual Flow

For each of the USGS gages the mean monthly flow and mean annual flow was computed for two different periods of record. For the East Branch Tully River and Millers River at Erving gages, the two periods selected represented pre and post Corps Dam construction. For Tarbell Brook, Millers River at Winchendon, Priest Brook and Moss Brook pre-1950 and post-1950 mean monthly flows were computed to identify any long-term trends in the data. Lastly, for those gages with short records (Otter River, Millers River at South Royalston, and Lake Rohunta outlet) only the full period of record was examined.

Bar graphs depicting the pre and post period of record are shown in the following figures. Also shown on the figures is the percent difference in flow relative to either the pre-Corps facilities or pre-1950 period of record. When reviewing the results keep in mind the 1960's drought, and the March 1936 and September 1938 flood events.

8.4.3-1 Tarbell Brook near Winchendon, MA
8.4.3-2 Millers River near Winchendon, MA
8.4.3-3 Priest Brook near Winchendon, MA
8.4.3-4 Otter River at Otter River, MA
8.4.3-5 Millers River at South Royalston, MA
8.4.3-6 East Branch Tully River near Athol, MA
8.4.3-7 Lake Rohunta Outlet near Athol, MA
8.4.3-8 Moss Brook at Wendell Depot, MA
8.4.3-9 Millers River at Erving, MA

East Branch Tully River- The operation of the Tully Lake flood control project has changed the seasonal distribution of flow in the East Branch Tully River, the Tully River, and the Millers River. Tully Lake Dam is operated to lower lake levels in the fall to capture the spring runoff. As Figure 8.4.3-6 shows, the post-dam mean monthly flows are higher in October, November and December than pre-dam conditions. In October, when the Tully Lake drawdown typically starts, the post-dam mean monthly flow is 42 % higher (net difference= 13.6 cfs or 0.27 cfsm) than pre-dam conditions. Likewise, in March, when the spring runoff typically occurs, the post-dam mean monthly flow is 23% lower (net difference=41 cfs or 0.80 cfsm) than pre-dam conditions as water is being stored. It is also interesting to note that during July, August and September, the pre-dam mean monthly flows were higher than post-dam flows (34%, 13 cfs in July, 14%, 4 cfs in August and 40%, 15 cfs in September). The lower summer flows could be the result of naturally lower precipitation and runoff, and/or the operation of Tully Lake. As noted earlier, operators strive to maintain relatively stable lake levels during the summer period, however, as shown later lake levels do fluctuate during the June-September period. Large runoff events are stored during this period as reservoir elevations increase. A comparison of pre/post-dam total average monthly precipitation at the Athol gage (the closest gage to Tully Lake) for July, August and September is shown in Table 8.4.3-1.

Table 8.4.3-1: Athol Precipitation Gage- Comparison of Pre/Post Dam Average Precipitation

Period of Record	July	August	September
1917-1947 (pre-dam)	4.21 inches	3.61 inches	4.18 inches
1951-2000 (post-dam)	3.88 inches	3.74 inches	3.52 inches
Net Difference in Precipitation (in inches) relative to pre-dam period of record	-0.33 inches (-7.9%)	+0.13 inches (+3.5%)	-0.66 inches (-15.8%)

As Table 8.4.3-1 shows, the pre-dam monthly precipitation was generally higher (except August), which could explain why pre-dam mean monthly flows were also higher. Further exploration of this subject matter is presented later in this report.

Millers River at Erving: The operation of Tully and Birch Hill Dams have changed the seasonal distribution of flow in the Millers River. Both Tully Lake Dam and Birch Hill Dam are operated to lower lake levels in the fall to capture the spring runoff. As Figure 8.4.3-9 shows, the post-dam mean monthly flows are higher in October, November and December than pre-dam conditions. The largest difference between pre and post-dam mean monthly flows occurs in October, when Tully Lake is drawn down. The pre-dam October mean flow is 400 cfs, and the post-dam mean flow is 287 cfs, a difference of 113 cfs (39.5% or 0.30 cfsm). During the refill period, the post-dam flows in March and April were less than pre-dam conditions.

Remaining Gages: The remaining gages are not directly affected by the operation of the Corps facilities. To evaluate long-term trends, the pre and post 1950 mean monthly flows are shown on the various figures. Human activities in these basins have occurred gradually over time and thus it is difficult to pinpoint an exact time when the timing of runoff due to human activities induced changed. Generally, mean monthly flows vary due to the operation of storage reservoirs in the basin. The gages examined here do not contain any large reservoirs that would result in shifting the timing and magnitude of flow. Because of the cumulative effect of long-term changes in the basin, coupled with the natural variability in precipitation (pre and post 1950) it is difficult to decipher if changes in the seasonal flow regime are attributable to human activities or precipitation changes. For example, during the months of June, July and September the pre-1950 mean monthly flows are less than the post-1950 period.

The pre/post 1950 mean flows for June, July and September for the Tarbell Brook, Millers River at Winchendon, Priest Brook and Moss Brook USGS gages are presented in Table 8.4.3-2. Also shown is the pre/post 1950 precipitation recorded at the Athol gage.

Table 8.4.3-2: Pre/Post 1950 Mean Monthly Flows at Tarbell Brook, Millers River at Winchendon, Priest Brook and Moss Brook. Pre/Post 1950 Precipitation at Athol Gage

	Tarbell Brook			Millers River @ Winchendon			Priest Brook			Moss Brook		
Month	Jun	Jul	Sep	Jun	Jul	Sep	Jun	Jul	Sep	Jun	Jul	Sep
FLOW												
pre-1950 flow (cfs)	26.0	14.8	14.0	123.6	76.7	74.4	29.1	15.4	15.2	18.2	9.2	5.6
post-1950 flow (cfs)	20.3	10.2	8.5	106.6	50.4	60.7	22.3	10.4	10.6	13.1	6.3	5.8
Net Difference relative to pre-1950 flow	-5.7 -22%	-4.6 -31%	-5.4 -39%	-17.0 -14%	-26.3 -34%	-13.7 -18%	-6.8 -23%	-4.9 -32%	-4.6 -30%	-5.1 -28%	-2.9 -32%	-2.0 -26%
PRECIPITATION as recorded at the Athol Gage												
pre-1950 precip (in)	4.65	4.10	4.00									
post-1950 precip (in)	3.51	3.88	3.51									
Net Difference relative to pre-1950 precipitation	-1.14 -25%	-0.22 -5%	-0.49 -12%									

As Table 8.4.3-2 shows the mean monthly flows are less during the post-1950 period of record. However, the mean monthly precipitation levels for post-1950 period of record are also less than the pre-1950 period. In summary, it is impossible to determine if human activities are playing a role in changing the mean monthly flows, as the flow patterns appear to follow precipitation levels.

8.4.4 Analysis of 2000 Hourly Hydrographs (and other Hydrographs for the East Branch of the Tully River and Millers River at Erving)

The Corps and USGS gage flow data was obtained on an hourly basis for calendar year 2000. The purpose for collecting this information was to evaluate the timing, magnitude and shape of the hydrograph at all gages. Daily and monthly hydrographs do not always illustrate the true hourly changes in flow that might occur, which affects the timing of flows. For this analysis, generally two sets of hydrographs were developed- 1) the entire calendar year of 2000 and 2) a low flow period extending from August 22 to September 6, 2000. As described in the findings below, many of the hydrographs for the August 22 to September 6 period reflect a regulated system as flow fluctuations occur on an hourly and/or daily basis. The hydrographs were evaluated to determine what potential sources of regulation might cause unnatural flow patterns, such as NPDES discharges, hydropower operations, or other sources. To assist in the discussion below, shown in Figure 8.4.4-1 is a Millers River Basin map with the following overlays: USGS gages, water withdrawals in excess of 100,000 GPD, NPDES discharge locations, and major dams. Understanding the geographic location of human activities (water withdrawals, dam locations and NPDES discharges) will assist in explaining the flow patterns at the USGS gages.

Also plotted on the August 22 to September 6, 2000 hydrographs are hourly precipitation totals (in inches) for the Fitchburg or Orange, MA recording gages. The Fitchburg gage is located in the northern part of the basin, while the Orange gage is located in the central part of the basin. The precipitation data, when plotted along with the flow data, helps to identify unnatural flow patterns.

In addition to the 2000 hourly hydrographs, additional hourly hydrographs of the Tully Lake and Birch Hill Lake projects were developed. The Corps provided hourly lake level and discharge data for a few years for both projects. These data were plotted on the same graphs such that the relationship between reservoir elevation and flow could be evaluated.

Priest Brook near Winchendon, MA (19.4 mi^2)
The USGS maintains a gage on Priest Brook, which is located three miles upstream of the confluence with the Millers River. USGS records indicate that prior to 1962, occasional diurnal fluctuation at low flow was caused by an upstream mill and prior to 1953, regulation occurred under low flow conditions by a mill and ponds. Dams are located above the Priest Brook gage, however, it is assumed that the operation of the dams does not cause hourly changes in flow. Shown in Figure 8.4.4-2 is the hourly annual hydrograph for calendar year 2000. There are no seasonally operated reservoirs upstream of the gage that would change the magnitude and timing of flows in Priest Brook. The annual hydrograph suggests that runoff from storm events occurs rapidly in the brook, as the hydrograph rises and falls quickly, a common occurrence in small drainage basins located on the watershed divide.

The hydrograph was further refined for the period August 22-September 16, 2000 as shown in Figure 8.4.4-3. The flow variability is consistent with a relatively unregulated river as flow does not vary abruptly on an hourly basis, rather flows naturally rise and fall in response to precipitation events. The Priest Brook flow record can be used as a benchmark of an unregulated river when compared to other gaged rivers in the basin.

Millers River near Winchendon, MA (81.8 mi^2)

The USGS maintains a gage on the Millers River near Winchendon, MA approximately 0.3 miles downstream from the confluence with Tarbell Brook. The USGS indicates that flow is regulated by upstream hydropower projects, Lake Monomonac and other reservoirs upstream. More specifically, upstream sources of hydropower regulation include Tannery and Hunts Pond (Whitney Pond has not operated as a hydropower station for several years), seasonal regulation by Lake Monomonac, as well as the discharge from the Winchendon Water Pollution Control Facility (WWPCF). Tannery and Hunts Pond are located in series further upstream of the USGS gage and have essentially the same drainage area of 54 mi^2. The WWPCF is located immediately upstream of the USGS gage.

Shown in Figure 8.4.4-4 is the hourly annual hydrograph for calendar year 2000. As the annual hydrograph shows, there is natural seasonal flow variability, however, minor hourly fluctuations occur during low flow periods. To investigate further, the same period of record (August 22-September 16, 2000) was evaluated at the Winchendon gage as shown in Figure 8.4.4-5. There is a pronounced flow fluctuation, however, it is unknown whether this is due to a) the Tannery and Hunts Pond hydroelectric projects, b) discharges from the WWPCF, c) tributary inflow reflecting pulsing releases or d) a combination of the above. The daily fluctuation ranges from 6 to 7 cfs. The WWPCF has a design discharge capacity of 0.50 MGD or 0.77 cfs, although the operator has indicated that they have discharged up to 1.8 MGD (2.8 cfs). Because the fluctuations are greater than the WWPCF facility's capacity it is possible that the upstream hydroelectric projects could be causing the fluctuations (and/or in combination with the WWPCF could be causing the fluctuations). Other possible causes of the flow fluctuations are other dams located upstream (on the mainstem or tributaries) of the gage site.

Otter River at Otter River, MA (34.1 mi^2)

The Otter River gage is located on the upstream side of Turner Street Bridge, 0.2 miles upstream of Baily Brook. The gage is located upstream of the Seaman Paper Company dam on the Otter River. Based on the available database there are no dams located on the Otter River mainstem upstream of the gage, however, several dams are located on tributaries upstream of the gage. Besides the dams, other upstream regulation includes the Gardner Wastewater Treatment Plant (GWWTP) and the Gardner DPW-Water Division water supply withdrawals (Otter River well and Crystal Lake).

Shown in Figures 8.4.4-6 and 8.4.4-7 are hydrographs for calendar year 2000 and for the period August 22 to September 16, 2000, respectively. Since there is no large seasonal regulation of flow upstream of the gage, the magnitude and shape of the seasonal hydrograph is reasonably close to an unregulated system. However, as Figure 8.4.4-7 illustrates, the flow does fluctuate once a day, varying by approximately 2 cfs. Possible reasons for this hourly variability are:

- the GWWTP has a design capacity of 5.0 MGD or 7.7 cfs (well within in the 2 cfs range). The time of the day of peak flow typically occurs in the morning, which matches the WWTP load as wastewater discharge is high at this time.
- the Gardner DPW-Water Division water supply withdrawal. The combined maximum daily withdrawal from the Otter River well and Crystal Lake is 3.02 MGD or 4.7 cfs. In most instances, water supply withdrawals typically remain constant over a day and likely would not cause diurnal flow fluctuations.
- other dams located on the tributaries upstream of the gage.

Millers River near South Royalston, MA (189 mi^2)
The USGS discontinued the South Royalston gage in 1990, although the Corps has continued to operate and maintain the gage. The gage is located downstream of Birch Hill Dam, and has a drainage area of 189 mi^2, whereas the drainage area at Birch Hill Dam is 175 mi^2. James Bacon, the Corps Project Manager for Birch Hill, indicated that three small streams enter between the dam and gage location. Carmen Suarez provided hourly flow data as measured at the South Royalston gage, as well as hourly lake level data. In some cases, there was some missing data from the record, thus some of the hydrographs end and start abruptly.

Shown in Figures 8.4.4-8, 8.4.4-9, and 8.4.4-10 are the Birch Hill Dam reservoir elevations and flows recorded at the South Royalston gage for calendar years 1999, 2000 and 2001, respectively. As the figures depict during the spring runoff period, Birch Hill Dam reservoir elevations increase, as water is stored, and are then lowered after the runoff period. Figure 8.4.4-9 (hourly data for 2000) is an example of how storage is used to reduce high flows. The reservoir elevation on February 18, 2000 was approximately 1.8 feet, but rises to a peak of 15.42 feet on April 7, a net gain of 13.94 feet. This volume of water represents 7,119 acre-feet or 3,686 cfs-days[31]. As noted earlier, the Corps strives to limit the flow at the Athol gage to 2,670 cfs (warning stage, flood stage is 3,155 cfs). During 2000, the maximum flow at the Athol gage was 2,591 cfs.

It is also interesting to note that the discharge gate openings are sometimes changed abruptly, presumably in response to high flow events. Shown in Figure 8.4.4-11 is an hourly hydrograph for the period March 15-April 16, 2000. As Figure 8.4.4-11 shows, on March 31 at 5:00 pm the flow was 208 cfs, and four hours later at 9:00 pm, the flow increased to 1,501 cfs (an upramp rate of 323 cfs/hour). Similarly, downramping occurs over short intervals. On April 2 at 10:00 am the flow was 1,347 cfs, and four hours later at 2:00 pm, the flow decreased to 215 cfs (a downramp rate of 283 cfs/hour). It is assumed that a slower downramping rate could be provided if the high flow event has passed and there were no concerns of downstream flooding.

Shown in Figure 8.4.4-12 is the August 22 to September 16, 2000 hourly hydrograph. Flows do not vary on an hourly basis; however, the dry-bed reservoir still provides some storage use (as evidenced by the August 25, 2000 precipitation event). On August 25, the flows ranged from 132 cfs at 7:00 am to 35 cfs at noon, and then back to 139 cfs at midnight. It is uncertain why there was a sudden shift in the release over this short time interval, although a short precipitation event could be the cause.

[31] Carmen Suarez from the Corps of Engineers provided the Birch Hill stage versus storage curve.

East Branch Tully River (50.5 mi^2)

Between Birch Hill Dam and the next gage on the Millers River several tributaries drain into the Millers River, including the Tully River. On the East Branch Tully River is the Corps Tully Lake Dam Flood Control Facility. The USGS maintains a gage just below the Tully Lake Dam. Similar to Birch Hill Dam, Carmen Suarez from the Corps also provided hourly lake level data for 1999-2001. There are no other dams or sources of regulation upstream of the Tully Lake Dam.

Shown in Figures 8.4.4-13, 8.4.4-14 and 8.4.4-15 are hourly hydrographs for 1999, 2000, and 2001, respectively. Similar to Birch Hill Dam, the figures illustrate how Tully Lake discharges are increased in the late fall/early winter to create storage for the spring runoff. Figure 8.4.4-14 (hourly data for 2000) is an example of the how storage is used to reduce high flows. During early March Tully Lake is storing water as the reservoir level increases. The reservoir elevation on March 6 is 10.22 feet, but rises to a peak of 18.33 feet on March 13, a net gain of 8.11 feet. This volume of water represents 1,807 acre-feet or 913 cfs-days[32].

Another interesting point is how gate changes are made abruptly at various times in a given year. For example, shown in Figure 8.4.4-16 is an hourly hydrograph for the period August 2-26, 2000. On August 12 at 9:00 am the flow was 18 cfs and 8 hours later, at 5:00 pm, the flow was 350 cfs (an increase of 332 cfs in 8 hours). Again, an hour later at 6:00 pm, the flow increased to 413 cfs, before peaking at 490 cfs on August 13 at 1:00 pm. In general, releases appear block loaded where discharges are maintained stable for a certain period of time, and then changed. For example, a release of 18 cfs is held constant over 20 days. Also on August 22 and 23, discharges were less than 10 cfs, the minimum flow (or-inflow, presumably because inflow fell below 10 cfs). The lake level does not vary over this time period, suggesting that the project is operated close to run-of-river. It should be noted, however, that the magnitude of discharge during this period represents only a minor portion of the storage capacity of the reservoir (i.e. discharges of 18 cfs will not change the Tully Lake level because the storage capacity is much greater).

Millers River in Athol, MA (280 mi^2)

The Corps operates and maintains a gaging station on the Millers River in Athol, MA, located downstream of the Tully River confluence, and downstream of three dams in Athol (in upstream to downstream order the dams are Cresticon Upper, Cresticon Lower, and Crescent Street Dam). It is speculated that this gage is subject to backwater effects from the New Home Dam and thus flows may not be representative. Given this caveat, the same hourly analysis was carried forward.

Shown in Figure 8.4.4-17 is the hourly annual hydrograph for calendar year 2000, which is influenced by the seasonal storage capacity of Birch Hill and Tully Lake flood control facilities. During the spring these flood control projects store inflow, which reduces the magnitude of flow observed at the Athol gage. Following the spring runoff, as flow in the Millers River starts to recede, the stored water is discharged from the Corps facilities. Thus the timing and magnitude of flow is shifted later in the spring, after the period of major runoff.

[32] Carmen Suarez from the Corps of Engineers provided the Tully Lake stage versus storage curve.

Shown in Figure 8.4.4-18 is the August 22 to September 16 hydrograph, which shows a 50-60 cfs fluctuation each day. Potential causes of the fluctuation are a) one or more of upstream hydropower projects is operating in a store-and-release mode, b) the downstream New Home dam water levels are fluctuated causing backwater affects at the gage and thus erroneous flow values, c) the Athol gage is operating incorrectly under low flow conditions, or d) one of many WWTP discharges (although this is unlikely given the range of pulse (50-60 cfs) relative to WWTP hydraulic capacity). It should be noted that discharges from Birch Hill Dam during the same period did not show hourly variability as observed at the Athol gage. For the two FERC exempt Cresticon projects, they are required to operate in an instantaneous run-of-river mode, and the Crescent Street dam is non-jurisdictional (it is assumed that this project should be operated as run-of-river as well).

Millers River at Erving, MA (372 mi^2)

The Millers River at Erving gage is located just downstream from the bridge at Farley, or approximately 2.4 miles downstream from Erving. Sources of regulation between the Athol and Erving gages include the New Home Dam hydropower project on the Millers River mainstem, other dams located on the Millers River mainstem and intervening tributaries, and WWTP discharges.

Shown in Figures 8.4.4-19 and 8.4.4-20 are the annual (2000) and August 22 to September 16, 2000 hydrographs, respectively. Also shown on Figure 8.4.4-20 are the Athol flows such that comparisons between the Athol (280 mi^2) and Erving (372 mi^2) hydrographs could be examined. It appears that the New Home hydropower project is pulsing releases by approximately 80 cfs. Although the inflow hydrograph to the Erving gage also reflects fluctuating flows the magnitude of variability (50-60 cfs as compared to 80 cfs) is less. In addition, whereas the Athol gage reflected one pulse each day, the Erving gage reflects two pulses each day. As noted earlier in the document, the New Home Dam is FERC exempt and is required to operate as an instantaneous run-of-river project. It should be noted that in 2001 and 2002 FERC has consulted with the New Home Dam owner, O'Connell Energy Group, regarding the operation of the project, specifically the lack of maintaining required minimum flows and pulsing operations (see Appendix B). The latest correspondence from FERC requires that the owners develop a streamflow compliance and monitoring plan with FERC. Although there are WWTP discharges between Athol and Erving, they collectively would not cause an 80 cfs swing in flows.

8.5 Indicators of Hydrologic Alteration (IHA)

Hydrologic regimes are vitally important in determining the composition, structure, and function of aquatic, wetland riparian ecosystems (Richter, et al). Human disturbance has resulted in changing natural hydrologic regimes in rivers across the country. In order to identify the impact of human disturbance on the hydrologic regime, the Nature Conservancy has developed "The Indicators of Hydrologic Alteration"(IHA) in 1996 (Richter, B., Baumgartner, J., Powell, J., Braun, D.). The IHA method assesses the degree of hydrologic alteration attributable to human influence within an ecosystem. The IHA software[33] evaluates 33 flow parameters to provide information on ecologically significant features of surface water regimes influencing aquatic,

[33] The IHA program utilizes mean daily flow data.

wetland and riparian ecosystems. The 33 flow parameters evaluate the timing, duration, frequency, magnitude and rate of change of flow conditions. It has the ability to assess hydrologic changes associated with activities such as dam operations, flow diversion, groundwater pumping, or intensive land-use conversion.

The IHA analysis was conducted on all USGS gages in the Millers River Basin (with 20 or more years of record) to supplement the analysis conducted in Section 8.4. There are two key features of the IHA analysis that may assist in identifying the effects of human disturbances on hydrologic regimes for the various USGS gages evaluated in Section 8.4. First, the program allows users to compare pre-impact and post-impact hydrologic regimes- such as before and after the Corps facilities were constructed. Second, many hydrologic systems experience a gradual, long-term accumulation of human impacts rather than a single impact such as a dam. To assist in the analysis of such cumulative impacts, the IHA program has developed graphical analysis and linear regression on data for such systems (called “trends” analysis). Both the pre- and post-impact analysis and trends analysis are described further below.

Based upon known human alterations to the hydrologic system (such as dates of dam construction), the IHA program allows users to compare hydrologic parameters between any two selected time periods—commonly called “pre-impact” and “post-impact” analysis. The results of this comparison between two time periods will generate the following results: (1) as graphs, illustrating the annual values of each parameter and the means and standard deviations; (2) as tabular output (IHA refers to this as the “scorecard”), with tables that summarize the central tendency (means) and dispersion (coefficient of variation). These are shown for the 33 parameters, and separately for pre-impact and post-impact periods. The tabular output will also summarize the differences in each of the 33 parameters between the pre- and post-impact periods; these differences are presented as both actual magnitudes and as percentages.

Shown in Table 8.5-1 is a summary of the grouping, hydrologic parameters, and ecosystem influences. This table was taken directly from the IHA manual (Richter, et al) and is not specific to the Millers River Basin. The ecosystem influences provide general information on what resources may be affected by changes in certain hydrologic variables. No site-specific information on the Millers River or its tributaries has been collected as part of this study. For example, it is unknown if the East Branch of the Tully River below the Corps Dam contains certain habitat features that would be influenced by the operation of the project—site specific data would have to be collected to determine the true impacts.

Table 8.5-1: Summary of Hydrologic Parameters used in the Indicators of Hydrologic Alternative and their Characteristics

IHA Statistics Group	Hydrologic Parameters	Ecosystem Influences
Group 1: Magnitude of Monthly Water Conditions	Mean value for each calendar month	-Habitat availability for aquatic organisms. -Soil moisture availability for plants. -Availability of flood/cover for fur-bearing animals. -Reliability of waters supplies for terrestrial animals. -Access by predators to nesting sites. -Influences water temperature, oxygen, photosynthesis in water column.
Group 2: Magnitude and Duration of Annual Extreme Water Conditions	Annual 1-day minima Annual minima, 3-day means Annual minima, 7-day means Annual minima, 30-day means Annual minima, 90-day means Annual 1-day maxima Annual maxima, 3-day means Annual maxima, 7-day means Annual maxima, 30-day means Annual maxima, 90-day means No. of zero-flows days (0 cfs)	-Balance of competitive, ruderal, and stress-tolerant organisms. -Creation of sites for plant colonization. -Structuring of aquatic ecosystems by abiotic vs. biotic factors. -Structuring of river channel morphology and physical habitat conditions. -Soil moisture stress in plants. -Dehydration in animals. -Anaerobic stress in plants. -Volume of nutrient exchanges between rivers and floodplains. -Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments. -Distribution of plant communities in lakes, ponds, floodplains. -Duration of high flows for waste disposal, aeration of spawning beds in channel sediments.
Group 3: Timing of Annual Extreme Water Conditions	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum	-Compatibility with life cycles of organisms. -Predictability/avoidability of stress for organisms. -Access to special habitats during reproduction or to avoid predation. -Spawning cues for migratory fish . -Evolution of life history strategies, behavioral mechanisms.

IHA Statistics Group	Hydrologic Parameters	Ecosystem Influences
Group 4: Frequency and Duration of High and Low Pulses	No. of low pulses within each year Mean duration of low pulses within each year No. of high pulses within each year Mean duration of high pulses within each year	-Frequency and magnitude of soil moisture stress for plants. -Frequency and duration of anaerobic stress for plants. -Availability of floodplain habitats for aquatic organisms. -Nutrient and organic matter exchanges between river and floodplain. -Soil mineral availability. -Access for waterbirds to feeding, resting, reproduction sites. -Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses).
Group 5: Rate and Frequency of Water Conditions Change	Means of all positive differences between consecutive daily values. Means of all negative differences between consecutive daily values. Number of hydrological reversals.	-Drought stress on plants (falling levels). -Entrapment of organisms on islands, floodplains (rising levels). -Desiccation stress on low-mobility streamedge (varial zone) organisms.

Group 1: monthly average values
Group 2: maximum and minimum values for 1- to 90-day averages.
Group 3: Julian dates (day of year) of the one-day minimum and maximum values.
Group 4: "pulses" in the water conditions. These are defined as periods when the water conditions are greater than the default or user defined high pulse (flood) threshold, or less than the low pulse threshold (also default or user-defined). There are four parameters the number of high and low pulses during the years, and their average duration. *As noted earlier the IHA analysis utilizes mean daily flows, thus hourly changes in flow may be masked somewhat with a daily time step. In summary, the true abrupt changes in flow may not be as obvious using a mean daily flow as opposed to an hourly flow.*
Group 5: rises, falls, and reversals in water conditions. There are three of these parameters: the average rate at which water levels or flow rises, the average rate of fall, and the number of times that the hydrograph switched from a rising to a falling condition or vice versa. This latter parameter is called the "number of reversals".

For the analysis below, the following definitions apply:

Base Flow is defined as the 7-day minimum flow/Mean Annual Flow
Low Pulses are defined as those periods during which daily mean flow drops one standard deviation below the period of record annual mean flow
High Pulses are defined as those periods during which daily mean flow rises one standard deviation above the period of record annual mean flow
Low Pulse Count is defined as the average number of days each year the mean daily flow drops one standard deviation below the period of record annual mean flow.
High Pulse Count is defined as the average number of days each year the mean daily flow rises one standard deviation above the period of record annual mean flow.

8.5.1 Evaluation of Pre- and Post-Corps Dam (IHA Analysis)

The Corps of Engineers Tully Lake and Birch Hill Flood Control facilities were constructed for the purpose of providing flood control to communities bordering the Millers and Connecticut Rivers. By providing flood protection, the facilities have greatly changed the seasonal runoff of water in the Millers River by either increasing discharges during the fall/winter and/or reducing discharges in the spring, as runoff is stored. In addition, as evidenced from hourly discharge records, flows can change abruptly due to gate operations. The IHA analysis was conducted on these two gages using the following periods of record:

East Branch of the Tully River: Pre-Tully Dam: 1917-1948 (32 years)
Post-Tully Dam: 1949-1989 (41 years)
Tully Dam was completed in 1949

Millers River at Erving: Pre-Birch Hill Dam: 1916-1940 (25 years)
Post-Birch Hill Dam: 1949-2000 (52 years)
Tully Dam was completed in 1949
Birch Hill Dam was completed in 1941

It should be noted that the results of the IHA analysis will reflect the pre- and post-Corps dam flow parameters, however, these same parameters will also reflect the cumulative effects of other human disturbances in the basin such as dams, water withdrawals, land use changes, etc. Readers should recognize that differences in the pre/post dam flow statistics are not solely the result of the Corps facilities as there are other human actions that have altered the natural hydrologic regime. Natural phenomena such as precipitation patterns/totals, and the amount of snowpack also influence river flow patterns.

The pre- and post-dam mean annual flow was computed for each gage to determine if there was approximately the same volume of water for both time periods. Similarly, the same exercise was applied to the long-term precipitation record. There was concern that the pre- or post-dam period may have a much higher or lower mean annual flow/precipitation that could also skew the results. However, as shown in Table 8.5.1-1 the mean annual flow and precipitation is very similar for the pre/post dam periods of record.

TABLE 8.5.1-1: Mean Annual Flow for Various Periods of Record: East Branch Tully River and Millers River at Erving

Period of Record	Mean Annual Flow (cfs)	Mean Annual Precipitation (in)
	East Branch Tully River	Athol Precipitation Gage
1917-1948 (32 years)	83.34 cfs	42.49 in
1949-1989 (41 years)	79.59 cfs	43.22 in
% Difference relative to pre-dam	-4.5%	+1.72%
	Millers River at Erving	Athol Precipitation Gage
1916-1940 (25 years)	625.44	43.10 in
1949-2000 (52 years)	644.63	43.45 in
% Difference relative to pre-dam	+3.1%	+0.80%

Many of the 33 parameters contained within the IHA analysis were examined in Section 8.4, thus there may be some duplication. However, for purposes of completeness, the full set of IHA results have been provided here for both gages. The IHA program can be operated in various modes. For purposes of evaluating pre/post dam analysis the "parametric" option was selected. In this option, for each IHA parameter, and for both the pre- and post-dam periods, the mean and standard deviation of annual values is calculated. For each plot, the mean and one standard deviation above and below the mean is shown (for both pre- and post-dam conditions).

We examine in more detail the IHA results for the East Branch Tully River and Millers River at Erving since these gages are subject to Corps operations. A distinct pre and post dam period exists in which to compare. For the remaining gages a trends analysis was conducted as explained further below.

8.5.1.1 IHA Results for East Branch Tully River

The following figures were developed:

Group 1: Figures 8.5.1.1-1 through 8.5.1.1-12: October-September mean monthly flows, respectively

Group 2: Figures 8.5.1.1-13 through 8.5.1.1-17: Annual minima 1-day, 3-day, 7-day, 30-day and 90-day, respectively.
Figures 8.5.1.1-18 through 8.5.1.1-22: Annual maxima 1-day, 3-day, 7-day, 30-day, and 90-day, respectively.
Figure 8.5.1.1-23: Base Flow

Group 3: Figures 8.5.1.1-24 through 8.5.1.1-25: Julian date of each annual 1-day maximum and minimum flow, respectively.

Group 4: Figures 8.5.1.1-26 through 8.5.1.1-27: No. of low pulses each year, and the low pulse duration (in days), respectively.
Figures 8.5.1.1-28 through 8.5.1.1-29: No. of high pulses each year, and the high pulse duration (in days), respectively.

Group 5: Figures 8.5.1.1-30 through 8.5.1.1-32: Rise Rate, Fall Rate, and No. of Reversals, respectively.

Because of the number of graphs that are generated from the IHA analysis, we have focused on evaluating any obvious trends in the data (rather than explaining every graph). In addition to the graphical output, the program produces summary results, referred in IHA as the "scorecard" as shown in Table 8.5.1.1-1. The scorecard or summary output provides the pre and post dam flow conditions, the net difference in flow (called the deviation factor), and the percentage difference.

The pre and post dam periods of record were defined as 1917-48 and 1949-1989 (Tully Lake Dam was constructed in 1948). It is interesting to note that the pre and post dam mean annual flow was 83.3 cfs and 79.6 cfs, respectively, thus both periods had very similar annual flow volumes.

In reviewing the Group 1 results, the seasonal operation of Tully Lake is clearly depicted in the results. The post-dam mean monthly flows are greater in October (36.7% higher) and February (44.9% higher), as compared to the pre-dam condition. This is the result of Tully Lake being drawn down during these months, which increases the flow above natural conditions. Likewise, during March, the opposite trend occurs as water is being stored to minimize flooding. The post-dam March flow is 26.7% lower than pre-dam.

The Group 2 parameters show that the post dam mean 1-, 3-, 7-, 30- and 90-day annual minimum flows are lower under post dam conditions by as much as 21.9, 8.7, 14.1, 13.2, and 11.7%, respectively. Although the percentages are high, the difference in flow magnitude is minimal. For example the post dam mean 1-day minimum flow is 3 cfs, whereas the same variable is 3.8 cfs for pre dam conditions (21.9% difference). Not surprising, the greatest differences occur between the pre and post dam mean 1-, 3-, 7-, 30- and 90-day annual maximum flows. The percent reduction in flow for the 1-, 3-, 7-, 30- and 90-day annual maximum flows is 41.8, 32.8, 22.1, 14.0, and 8.3%, respectively. In this case, the magnitude difference between the pre and post dam maximum flows is considerable. For example, the mean 1-day pre and post dam maximum flows are 858.7 and 499.5 cfs, respectively. Again, this is the result of operating Tully Lake as a flood control facility.

The timing of the annual 1-day minimum flow also changed from September 9th under pre-dam conditions to August 21st under post-dam conditions, a shift of approximately 16 days. However, a more dramatic shifting in the timing of the annual 1-day maximum flow occurred, which again was not surprising given the flood control operation. The annual 1-day pre and post dam maximum flow occurred on March 23rd and May 6th, respectively, a shift of approximately 45 days later. Before the flood control facility was constructed the timing of the high runoff occurred in March, however, by storing large inflows during the spring runoff, it has shifted the peak flows to later in the year.

The low and high pulse count and duration were similar between pre and post dam conditions. Similarly, the average rate of rise and fall of the mean daily flow was similar. The rate of rise/fall analysis is somewhat misleading in the IHA analysis since it is based on average daily flows. As evidenced in the hourly analysis conducted earlier, gate changes can occur over short periods of time (minutes) and can become dampened by using a daily time step evaluation in IHA.

8.5.1.2 IHA Results for Millers River at Erving

The Millers River at Erving gage is regulated by both the Tully Lake and Birch Hill Flood control facilities. The pre-dam period of record was defined as 1916-1940 (Birch Hill Dam was constructed in 1941) and the post-dam period of record was defined as 1949-1989 (Tully Lake Dam was constructed in 1948).

The following figures were developed:

Group 1: Figures 8.5.1.2-1 through 8.5.1.2-12: October-September mean monthly flows, respectively

Group 2: Figures 8.5.1.2-13 through 8.5.1.2-17: Annual minima 1-day, 3-day, 7-day, 30-day and 90-day, respectively.
Figures 8.5.1.2-18 through 8.5.1.2-22: Annual maxima 1-day, 3-day, 7-day, 30-day, and 90-day, respectively.
Figure 8.5.1.2-23: Base Flow

Group 3: Figures 8.5.1.2-24 through 8.5.1.2-25: Julian date of each annual 1-day maximum and minimum flow, respectively.

Group 4: Figures 8.5.1.2-26 through 8.5.1.2-27: No. of low pulses each year, and the low pulse duration (in days), respectively.
Figures 8.5.1.2-28 through 8.5.1.2-29: No. of high pulses each year, and the high pulse duration (in days), respectively.

Group 5: Figures 8.5.1.2-30 through 8.5.1.2-32: Rise Rate, Fall Rate, and No. of Reversals, respectively.

Similar to the East Branch of the Tully River analysis, because of the number of graphs, we focused on obvious trends in the data. The IHA scorecard for the Millers River analysis is shown in Table 8.5.1.2-1.

Many of the trends observed for the East Branch Tully River gage are repeated for the Millers River at Erving gage. The mean monthly flows for pre and post dam conditions reflect the seasonal regulation of both Corps facilities. The post-dam mean monthly flows are greater in October (37.1% higher) November (21.1%) and February (35.8%), as compared to the pre-dam condition. Similarly, during March (9.1% lower), the opposite trend occurs, as water is stored at both Corps facilities. It is interesting to note that the post dam mean monthly flows for July (28.5% lower), August (16.3%) and September (38.4% lower) are lower than pre dam conditions. This could be the result of storing summer precipitation events. This same trend was observed at the East Branch Tully River gage as well.

The Group 2 parameters show that the post dam mean 3-, 7-, 30- and 90-day annual minimum flows are lower under post dam conditions by as much as 6.4, 25.0, 25.0, and 19.4%, respectively. Interestingly, the 1-day minimum flow was higher under post dam conditions (50 cfs) versus pre-dam (31 cfs) conditions. Perhaps, some low flow augmentation is provided from the Corp facilities over short time intervals of a day or two. As expected, the maximum flows (for 1, 3, 5, 7, 30 and 90-days) were considerably reduced under post dam conditions. For example, the one-day maximum annual flow for pre and post dam conditions was 5,373 cfs, and 3,396 cfs, respectively, a difference of 1,977 cfs (37%).

The timing of the annual 1-day minimum flow also changed from September 23th under pre-dam conditions to August 28st under post-dam conditions, a shift of approximately 24 days.

Interestingly, the timing of the annual 1-day maximum flow did not change- from May 12th (pre-dam) to May 13 (post-dam). Whereas more of a shift in the timing of maximum flows occurs on the East Branch Tully River, this was not observed on the Millers River. A potential explanation is the location of the gage relative to sources of regulation. The East Branch Tully River gage is located directly below Tully Lake, whereas the Millers River gage in Erving has considerable intervening drainage between the gage and Corps facilities. There is approximately 147 mi^2 (40%) of drainage into the Erving gage that is not subject to Corps regulation.

Similar to the East Branch Tully River, the low and high pulse count and duration were similar between pre and post dam conditions. The rate of rise changed from 154 cfs/day under pre-dam to 136 cfs/day under post-dam, an 11.6% difference. Of more significance is the rate of fall, which changed from –115 cfs/day to –75.3 cfs/day (34.5 % difference) under pre and post dam conditions, respectively. Operation of the Corps facilities or other sources of regulation has reduced the natural rate of rise and fall of the hydrograph.

8.5.2 IHA Analysis for Remaining Gages

As noted above, many hydrologic systems have experienced a long-term accumulation of human modifications rather than a temporally discrete impact such as a dam. When operating the program in the "trends" analysis mode, it is assumed that there is no exact impact date. Rather, trend graphs of the IHA parameters are produced together with a linear regression analysis of the data. A best-fit line (linear) is placed through the dataset such that trends, such as a long-term increase or decrease in flow, can be identified. Along with the linear regression line is the slope (positive or negative) and the y-intercept. We keyed off of the slope of the regression line as it provides an indication as to whether the trend showed a long-term increase (positive slope) or decrease (negative slope) in flow over the respective period of record.

The following gages were evaluated using the trends analysis mode:

- Millers River near Winchendon, MA (Oct 1917-Sep 2000)
- Priest Brook near Winchendon, MA (Oct 1919-Sep 2000)
- Tarbell Brook near Winchendon, MA (Oct 1917-Sep 1983)
- Moss Brook at Wendell Depot, MA (Oct 1917-Sep 1982)
- Otter River at Otter River, MA (Oct 1965-Sep 2000)
- Lake Rohunta Outlet near Athol, MA (Oct 1965-Sep 1985)
- Millers River at South Royalston, MA (Oct 1940-Sep 1990)

The gages were grouped according to their approximate period of record. The grouping was done such that common trends could be observed for relatively common periods of record. For example, the Tarbell Brook gage showed a long-term increase in the October mean flow. By comparing the Tarbell Brook gage with the Moss Brook gage (gages with similar records and drainage area sizes), the October mean flow trend can be compared. If the Moss Brook gage also shows a general increase in the October flow, then perhaps the trend is the result of natural hydrologic variability. However, if the October flow were to decrease, then some source of regulation is likely occurring in one of two gages. In this example, the Moss Brook October mean flow also increased, thus it is likely the result of natural hydrologic variability.

Because of the number of graphs (33 for each gage x 7 gages or 231 graphs), we have included the results in Appendix D. Rather than describe the results of each graph, emphasis was placed on comparing trends (general increase or decrease in flow over time) for gages of similar duration. It should be noted that although two gages may have similar periods of record, they could also have large differences in drainage area- specifically Priest Brook and the Millers River at Winchendon, which have similar periods of record, have different size drainages. Basin size plays a role in streamflow dynamics, with smaller basins typically having lower base flows and flashy runoff events. Alternatively, larger basins typically have higher base flows and are slower to respond to runoff events. Response time also depends on steepness of the watershed topography.

Shown in Table 8.5.2-1 is a summary of the IHA results for the remaining gages- the table contains the gage name, drainage area, period of flow record, and whether the flow increased (positive slope) or decreased (negative slope) over time. The actual slope is shown in Table 8.5.2-1 and slopes shaded in gray represent increasing flow (or day) over time.

Table 8.5.2-1: IHA Results for Remaining USGS Gages. Linear Regression Slopes from IHA analysis. Positive Slope indicates increasing flow or days. Negative Slope indicates decreasing flow or days.

Gage	Drainage Area (sq mi)	Period of Record	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Tarbell Brook	17.8	1917-1983	0.088	-0.029	-0.004	0.078	0.182	-0.010	-0.026	-0.073	-0.056	-0.090	-0.097	-0.150
Moss Brook	12.1	1917-1982	0.079	-0.074	-0.084	0.011	0.102	-0.203	-0.149	-0.159	-0.126	-0.075	-0.019	-0.041
Millers Winchendon	81.8	1917-2000	1.189	0.695	0.739	0.565	0.493	-0.037	-0.064	-0.143	-0.026	-0.431	-0.252	-0.297
Priest Brook	19.4	1919-2000	0.138	0.067	0.097	0.145	0.236	0.077	-0.246	-0.091	-0.052	-0.045	0.006	-0.035
Otter River	34.1	1965-2000	0.892	0.515	0.330	0.680	0.122	-0.003	-0.511	-0.204	-0.431	-0.090	0.379	0.332
Lake Rohunta	20.3	1965-1985	1.442	1.413	0.922	1.252	1.622	1.469	0.694	-0.151	0.675	0.161	-0.088	0.133
Millers Royalston	189	1940-1990	4.054	2.213	2.783	0.308	2.885	1.517	0.723	-0.616	1.203	0.862	1.403	0.612

Gage	Drainage Area (sq mi)	Period of Record	1-day min	3-day min	7-day min	30-day min	90-day min	1-day max	3-day max	7-day max	30-day max	90-day max	Base Flow
Tarbell Brook	17.8	1917-1983	-0.014	-0.028	-0.033	-0.037	-0.055	-0.900	-0.513	-0.270	-0.061	-0.011	-0.001
Moss Brook	12.1	1917-1982	-0.004	-0.006	-0.010	-0.006	-0.022	-0.661	-0.653	-0.428	-0.216	-0.157	0.000
Millers Winchendon	81.8	1917-2000	0.044	-0.090	-0.199	-0.231	-0.138	1.286	1.563	1.434	0.323	0.153	-0.001
Priest Brook	19.4	1919-2000	-0.007	-0.010	-0.015	-0.016	0.005	-1.036	-0.559	-0.322	-0.154	-0.070	-0.001
Otter River	34.1	1965-2000	0.053	0.057	0.050	0.068	0.194	-1.313	-1.090	-1.158	-0.494	-0.123	0.003
Lake Rohunta	20.3	1965-1985	-0.104	-0.099	-0.094	-0.076	0.015	6.878	5.423	3.100	0.915	1.013	-0.006
Millers Royalston	189	1940-1990	0.316	0.272	0.260	0.491	0.775	-0.371	0.948	2.569	1.199	1.374	0.000

Gage	Drainage Area (sq mi)	Period of Record	Julian Date 1-day min flow	Julian Date 1-day max flow	Low Pulse Count	Low Pulse Duration	High Pulse Count	High Pulse Duration	Rise Rate	Fall Rate	Reversals
Tarbell Brook	17.8	1917-1983	0.020	-0.402	-0.120	0.214	0.007	-0.023	0.006	0.035	-1.077
Moss Brook	12.1	1917-1982	-0.071	-0.237	0.020	0.009	0.003	-0.037	0.006	0.006	-0.333
Millers Winchendon	81.8	1917-2000	-0.754	0.384	-0.344	0.232	0.010	0.004	0.038	0.219	-1.158
Priest Brook	19.4	1919-2000	-0.294	0.307	-0.079	0.091	0.025	-0.017	0.042	0.034	-0.541
Otter River	34.1	1965-2000	-0.241	2.855	-0.096	0.324	0.079	-0.070	0.105	0.071	0.405
Lake Rohunta	20.3	1965-1985	-5.522	3.710	-0.001	-0.009	0.023	0.230	0.016	0.153	-0.223
Millers Royalston	189	1940-1990	-0.713	-0.844	-0.121	0.041	0.055	-0.053	0.582	0.024	-0.925

Tarbell Brook/Moss Brook

The trends experienced at these gages were virtually the same, except for the Julian date of the 1-Day min flow and the low pulse count. Overall, the trends observed at these gages are likely a function of natural flow conditions rather than a human activity since the trends were the same.

Millers River at Winchendon/Priest Brook

The Millers River at Winchendon and Priest Brook have similar periods of flow record, however, the drainage area sizes are very different. With respect to the mean monthly flows, both gages reflect similar trends except during August (Priest Brook flows are slightly increasing over time compared to the Millers River at Winchendon). Other trend differences occur for the 1, 3, 7, 30, and 90-day maximum flows with the Millers River at Winchendon showing a general increase.

Other Gages and General Interpretation

In general it is difficult to pinpoint why gages experience different trends due to a variety of issues including a) size, aspect, and slope of the basin, b) period of flow record examined in IHA, c) differences in geology, topography and land development, d) differences in human activities such as dams and water withdrawals within each basin and when potential changes occurred, etc. It is difficult to decipher from the trends analysis whether trends are the result of human activities or natural hydrologic variability.

9.0 Impacts of Human Activities on Aquatic Resources

In the above sections, the various human activities that affect the natural flow regime in the Millers River Basin and its tributaries were discussed. The major human activities in the basin that affect flow include dam operations, and water withdrawals. In this section, we highlight how human activities have potentially affected aquatic resources in the basin. It should be noted that the potential impacts described below are general to all streams and rivers and not specific to the Millers River. As noted earlier, no site-specific field data was collected as part of this study to further refine potential impacts.

General

The construction of dams on the Millers River and its tributaries are likely the largest contributor to flow regulation in the basin. Massachusetts's dams were built over the last two centuries to meet many historical and individual needs. Dams in the Millers River Basin serve a variety of purposes including water supply, flood control, hydropower generation, and recreation. Many dams create ponds or reservoirs that are often important aesthetic amenities to residents and visitors and provide opportunities for quiet-water canoeing, boating and fishing. Although many dams serve a vital role they can also have an impact on various natural resources including fish, wildlife, wetlands, water quantity and quality, aesthetics, archeological, etc. It is not the intent of this report to evaluate the merits of dams, but rather to focus on some of the concerns in the Millers River Basin.

Dams- Fish Passage

The Millers River Basin lies within the larger Connecticut River Basin, which has been subject to a long-term effort to restore Atlantic salmon to the Connecticut drainage. Atlantic salmon are anadromous, migrating from the ocean to fresh water specifically to reproduce. In the Connecticut River system, most adults migrate from the ocean to the river in the spring and spawn in swift-running, gravelly tributaries in October and November. The eggs hatch in March and April, and after three to four weeks under the gravel, fry emerge to seek food and establish feeding territories. Young salmon, called parr, spend one to three years in their natal stream, until they are about 6 inches long. Now called smolts, they undergo physiological and behavioral changes (so they can live in saltwater), and then migrate to the ocean.

There are several dams on the Connecticut River that have been fitted with upstream passage facilities to allow adult salmon to migrate upstream. Upstream passage is currently provided by the five most downstream dams on the Connecticut River, allowing Atlantic salmon and other anadromous fish such as American shad, to migrate to the Millers River (or move further up the Connecticut River). Currently, no upstream fish passage facilities are established on the Millers River mainstem dams. However, Atlantic salmon fry are routinely stocked in the Millers River (between South Royalston and Athol). To facilitate downstream migration of smolts, downstream fish passage facilities are needed. Based on discussions with the USFWS, the first three dams on the Millers River mainstem (from its confluence with the Connecticut) have downstream fish passage facilities in place. As of September 2002, New Home Dam (first dam on Millers River) has downstream fish passage facilities on the north side of the dam, but not the south side. Above New Home Dam is the L.S. Starrett Dam, which is currently non-jurisdictional, meaning that the USFWS does not have authority to require downstream passage. However, the next two upstream facilities, Cresticon Lower and Cresticon Upper are fitted with downstream passage facilities. There are no other dams between the stocking location and Cresticon Upper. Thus smolts that move downstream in the spring have passage at three of the four dams.

Pulsing Flows

As discussed in Section 8.0, pulsing flows occur at various locations in the watershed including the Otter River, and the Millers River near Winchendon, Athol and Erving. Pulsing flows, depending on the magnitude of flow fluctuation, can have significant impacts on aquatic resources by causing fish and macroinvertebrate stranding, reducing available aquatic habitat and affecting spawning grounds.

At high flows fish may feed on the stream margin, and as flows drop fish could become stranded in elevated pools leaving them susceptible to predation, and elevated water temperatures. The pulsing effect is more dramatic for low-mobility species such as macroinvertebrates and small fish. Macroinvertebrates and small fish may also colonize on the stream margin and are susceptible to wet/dry cycles from the pulsing flow. Without the ability to move closer to the center of the river and remain inundated, these organisms could desiccate and die. Macroinvertebrates and small fish serve a vital role in the overall ecology of the river, by providing a food source to fish and other species.

The quantity and quality of available habitat for fish and other aquatic organisms continuously changes as flows are pulsed. Depending on the species and life stage of fish, and range of flow fluctuation, the low end of the pulse can reduce the available habitat area. Under low flow conditions, the quality/quantity of habitat typically diminishes as water depths, and velocities decrease. Alternatively, the high end of the pulse could limit the quality/quantity of habitat for species that cannot tolerate high velocities.

Another concern with pulsing flows is the effect on spawning. Pulsing operations can damage incubating eggs or larval fish by scour (high flow) or desiccation (low flow). Resident species such as smallmouth bass, brown, brook and rainbow trout spawn in the Millers River, with the majority of salmonid spawning occurring in the fall (some like rainbow trout spawn in the spring). Eggs that are deposited along the stream margin under high flows can become exposed as flows subside leading to potential desiccation and death. Also, pulses at the high end can detach eggs or young fish from their nests leaving them suspended in the water column where predation may occur.

Rate of Change (Up Ramping/Down Ramping)

As noted earlier all of the mainstem dams on the Millers River (except Birch Hill Dam) are to be operated where inflow instantaneously equals outflow. Thus the rate of rise and fall of the hydrograph should be the same above and below these facilities. The Corps Tully and Birch Hill Dam facilities currently have no requirement on the rate in which discharges can be increased or decreased. As illustrated in the 2000 hourly hydrographs, discharges can change abruptly over a few hours, which can directly affect aquatic resources below the facilities. The impacts are similar to those described above for pulsing releases- fish and organism stranding, spawning concerns, reduction in the quality/quantity of fish habitat, etc. Maintaining an up and down ramping rate during non-flood periods would help to alleviate some of the potential impacts.

Flushing Flows

Increasingly, instream flow requirements also include provisions for flushing flows, deliberate high flow releases of short duration designed to mimic the effects of natural floods. The purpose of these high flow releases, which typically occur in the spring, are to remove fine sediment accumulated on the bed (especially in spawning gravels), to maintain fish spawning and rearing habitat, and to maintain channel conveyance capacity. The Tully and Birch Hill facilities were developed to reduce natural floods; however, there are instances when discharges are deliberately increased for special whitewater events such as the River Rat race in April. It is unknown if these special discharges are sufficient to remove fine sediments from spawning gravels.

Seasonal Minimum Flows

Depending on the habitat characteristics and the species/life stage of fish, adequate flows are necessary year-round to maintain habitat conditions in the river. Low flows will stress aquatic life and limit available habitat, while high flows may destroy potential habitat areas. These effects are most acute during low flow and poor water quality periods, such as late summer.

For the FERC-exempt projects on the Millers River mainstem, the facilities are to be operated where inflow instantaneously equals outflow, thus discharges from these projects should mimic inflow. Many of the facilities include bypass reaches, where minimum flow requirements have already been established by the USFWS.

For the Tully and Birch Hill Dams, year-round minimum flows of 10 cfs (0.20 cfsm) and 25 cfs (0.14 cfsm) are required, respectively. These minimum flow rates are low, relative to the seasonal minimum flows suggested by the USFWS in their New England Regional Flow Policy. The Policy sets default minimum flows on a flow per square mile basis if no long-term[34] USGS gage (reflecting unregulated conditions) or site-specific study (such as an Instream Flow Study) has been conducted.

The USFWS has used historical flow records for New England to describe streamflow conditions that will sustain and perpetuate aquatic fauna. Low flow conditions occurring in August typically result in the most stress to aquatic organisms, due to high water temperatures, and low dissolved oxygen, food supply and available habitat area. Over the long term, stream organisms have evolved to survive these periodic adversities without major population change. The USFWS has therefore designated the median August flow as the Aquatic Base Flow (ABF)[35].

[34] The long-tem unregulated flow record must be at least 25 years long.
[35] The ABF is derived from the average of the median August monthly flow records.

The USFWS has assumed that the ABF will be adequate throughout the summer (at a minimum), unless additional flow releases are necessary for fish spawning and incubation.

To maintain a more natural hydrograph below the Corps facilities, minimum flows could be implemented on a seasonal basis. Based on the default minimum flows set forth in the policy, the computed minimum flows for Tully and Birch Hill Dams would be higher than the current year-round minimum flow as shown in Table 9.0-1.

Table 9.0-1: USFWS New England Regional Flow Policy. Default Minimum Flows at Tully and Birch Hill Dams

Period	Fall/Winter (Oct-Mar)	Spring (Apr)	Summer (May-Sept)
Flow per square mile	1.0 cfsm	4.0 cfsm for the entire applicable spawning and incubation periods	0.5 cfsm as derived from the median August Flow
Tully Dam (50 mi^2)	50 cfs	200 cfs	25 cfs
Birch Hill Dam (175 mi^2)	175 cfs	700 cfs	88 cfs

Exceptions to the seasonal minimum flow are likely warranted during flooding periods. For example, spring minimum flows could be reduced to help alleviate downstream flooding.

As noted above, if there are over 25 years of unregulated flow data available (reflecting pre-dam unregulated flow conditions), the policy allows for seasonal minimum flows to be determined using observed flow data. There are 32 years of unregulated flow record on the East Branch Tully River (1917-1948, Tully Dam was constructed in 1949). No unregulated flow record is available for the Millers River at the South Royalston USGS gage located below Birch Hill Dam. The computed summer ABF flow[36] at Tully Dam, using the 32 years of unregulated flow record, is 12.4 cfs or 0.25 cfsm (as compared to the current 10 cfs or 0.20 cfsm).

Although there is no completely unregulated period of flow record on the Millers River mainstem before the Corps facilities were constructed (since many dams were in place during the early 1900's), the Winchendon and Erving gages have lengthy pre-Corps dam periods of record worth investigating. The same analysis conducted above for the East Branch Tully River was applied to the Millers River at Winchendon and Erving gages for the period 1917-1940 (24 years). As noted above although the Corps facilities were not constructed during this period, other sources of upstream regulation occurred, but the level of regulation was likely less. Given this caveat the median August flow (ABF flow) at the Winchendon[37] and Erving USGS gages

[36] The ABF is derived from the median of the average August monthly flow records (per the New England Regional Flow Policy). If the median of all daily August flow values were used the ABF values would be lower as follows: East Branch Tully River for period 1917-48- 9.6 cfs or 0.19 cfsm, Millers River at Winchendon for period 1916-40- 54 cfs or 0.66 cfsm and the Millers River at Erving for period 1916-40- 166.0 cfs or 0.45 cfsm.

[37] The Winchendon gage is located upstream of Birch Hill Dam. However, the same period of available record (1917-40) as the Erving gage was used for comparison purposes.

was 52.8 cfs (0.66 cfsm) and 173.9 cfs (0.47 cfsm), respectively[38]. Shown in Table 9.0-2 is the median of the average monthly flows and flow per square mile for the three USGS gages.

Table 9.0-2: Median of the Average Monthly Flows (cfs) and the Corresponding Flow per square mile (cfsm) for the East Branch Tully River and Millers River near Winchendon and Erving under Pre-Corps Dam conditions.

River/Period of Record	Median of the Average Monthly Flow in cfs (Pre-Corps Dams) & Flow per square mile in cfsm											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East Branch, Tully River (1917-48), cfs	72.5	52.6	173.8	200.6	112.2	62.1	29.4	12.4	14.1	26.6	60.4	58.7
East Branch, Tully River (1917-48), cfsm	1.44	1.04	3.44	3.97	2.22	1.23	0.58	0.25	0.28	0.53	1.20	1.16
Millers River at Winchendon, MA (1916-40), cfs	122.4	125.8	259.4	366.9	155.6	92.6	63.1	52.8	51.2	57.1	89.6	109.2
Millers River at Winchendon, MA (1916-40), cfsm	1.50	1.54	3.17	4.49	1.90	1.13	0.77	0.66	0.63	0.70	1.10	1.33
Millers River near Erving, MA (1916-40), cfs	603.9	493.6	1,207	1,673	835.4	444.0	273.8	173.9	210.1	289.2	410.2	541.2
Millers River near Erving, MA (1916-40), cfsm	1.62	1.33	3.24	4.50	2.25	1.19	0.74	0.47	0.56	0.78	1.10	1.45

Based on Table 9.0-2, the seasonal flow per square mile was computed (for the three gages) for comparison to the default flow per square mile (as shown in Table 9.0-1). The cfsm values shown in Table 9.0-3 were computed by selecting the lowest cfsm value for each season. For example, the lowest flow per square mile during Oct-Mar in the East Branch Tully River occurred in October- 0.53 cfsm.

Table 9.0-3: Summary of Seasonal Minimum Flows (on cfsm basis) based on New England Regional Flow Policy

River	Oct-Mar (Fall/Winter)	April (Spring)	May-Sep (Summer)
East Branch Tully River	0.53 cfsm	3.97 cfsm	0.25 cfsm
Millers River at Winchendon	0.70 cfsm	4.49 cfsm	0.66 cfsm
Millers River at Erving	0.78 cfsm	4.50 cfsm	0.47 cfsm
Default Values	1.00 cfsm	4.00 cfsm	0.50 cfsm

[38] The method of computing the ABF flow has varied among parties. The USFWS method computes the mean monthly flow, and then selects the median value from the array of annual August means. Another method relies on selecting the median flow value among all August average daily flows for the period of record. Using the second method results in minimum flows as follows: East Branch Tully River for period 1917-48- 9.6 cfs or 0.19 cfsm, Millers River at Winchendon for period 1916-40-54 cfs or 0.66 cfsm and the Millers River at Erving for period 1916-40- 166.0 cfs or 0.45 cfsm.

Exceptions to the seasonal minimums are likely warranted at the Corps facilities during flooding periods. For example, spring minimum flows could be reduced to help alleviate downstream flooding.

Besides dams, water withdrawals throughout the year also affect the timing and magnitude of flow in river reaches below the withdrawal point. The reduction in flow caused by withdrawals could have various effects such as: reduction in fish/macroinvertebrate habitat, increased water temperatures, poor water quality, etc. There is little water supply storage capacity, such as reservoirs, in the Millers River Basin, which could supply supplemental summer water demands, when flows are typically low.

Reservoir Operations

Tully Lake, Birch Hill Reservoir and other impoundments in the Millers River watershed have water levels that fluctuate. Changing water levels, beyond the natural cycle, can have an impact on an array of natural resources. For example, several impoundments including Tully Lake, Lake Monomonac, Lower Naukeag Lake and Sunset Lake reduce water levels in the fall and are refilled in the spring. The magnitude of drawdown varies, with a facility such as Tully Lake having a larger drawdown. Potential effects of a fall drawdown include a) fish spawning along the shoreline and the potential for exposure when the drawdown occurs, b) reservoir tributaries may be inaccessible for spawning fish, c) wetlands surrounding the impoundment could become dewatered, and d) loss of aquatic vegetation and littoral zone feeding area. It is unknown if any of these potential impacts are present at those impoundments experiencing a fall drawdown.

10.0 Recommendations

Based on analyses conducted above, several recommendations have been developed that can further refine the analysis. In addition, recommendations are provided in terms of reducing the effects of human manipulations on streamflow and aquatic resources.

- It is recommended that all public water suppliers and industrial water users develop up-to-date water conservation plans to help reduce the need for increased withdrawals. Water suppliers should strive to maintain residential water consumption to 80 gpcd and limit unaccounted-for-water to 10%.

  As described in the report, there are many instances where the reported residential water consumption or unaccounted for water (UAW) is inaccurately reported. For example, one water supplier showed residential water use as low as 26 gpcd. A value this low is likely inaccurate and is a function of how the population served is computed or estimated. Similarly, some water suppliers assumed that the water used for fire hydrant flushing or fire fighting was part of their UAW. According to MDEP, these sources are not considered UAW. It is recommended that reporting requirements for the population served and UAW be improved to allow the MDEP and others to better manage water supplies.

- Although the forecasted water demands for the various public water suppliers in the region do not show a dramatic increase, it is recommended that municipalities start the planning process to identify solutions to meet future demands. In addition, there is limited storage capacity in the Millers Basin that could be used to meet demands during the summer, when flows are low. Storage reservoirs would ideally limit the need to increase summer withdrawals and thus lessen the impact on streamflow and hence aquatic resources. Potential options could include:

  1. Increasing withdrawals (surface or groundwater) at existing withdrawal locations (provided the safe yield is not already fully tapped),
  2. Creating new withdrawal locations within the Millers River basin,
  3. Importing water from outside the Millers River basin,
  4. Creation of new storage reservoirs to store the spring runoff, and augment summer demand by drafting water from storage,
  5. For existing water supply reservoirs, consider raising the dam elevation to create additional storage, provided that the safe yield of the basin is not already fully tapped,
  6. Developing small storage tanks for subdivisions to provide non-potable, outdoor water supply to offset summer demands,
  7. Develop man-made storage tanks for additional reserve.

  The pros and cons of developing additional water supplies would also have to be evaluated in terms of regulatory hurdles, permitting process, hydrologic evaluations, environmental impact analysis, economics, and the political landscape.

- An evaluation of the existing wastewater treatment facilities would also have to be considered to determine if the facility can treat future increased waste loads. Reduction of inflow/infiltration to the wastewater collection system would restore system capacity and prevent the loss of groundwater, which would normally flow slowly to the rivers, providing summer base flow.

- The study evaluated stress levels in the certain subbasins using the criteria developed by the State. The determination of stress level was based solely on low flow statistics. The evaluation does not consider many other factors that play a role in river stress such as dam operations, water quality or instream habitat. For example, the stress level in a particular river reach may be considered low using the classification system, however, dam operations may result in a pulsing discharge where flows fluctuate over 50 cfs in a day, or water quality is considered poor. These factors would likely change the stress level to high. It is recommended that further evaluation of the subbasin stress levels evaluated in this study is needed.

- Operation of the FERC-exempt mainstem dams (excluding Birch Hill Dam) should be as run-of-river facilities. New Home Dam, the lowermost dam is currently in the process of rectifying the pulsing flows below their project with the FERC. In addition, pulsing flows were observed in the 2000 hourly hydrographs in the Otter River and in the Millers River near Winchendon and Athol. It is difficult to pinpoint what human activity is causing the pulsing flows, however, further investigation is recommended. The goal is to reduce the artificial pulsing that has historically occurred to match natural flow variability. To ensure run-of-river operations it is recommended that all dam operators install, calibrate and maintain a continuous streamflow monitoring gage to ensure compliance. It is recognized that there is a substantial cost to install a streamflow monitoring gage, so further discussions with dam operators is warranted to determine other methods to demonstrate compliance with run-of-river operations.

- This study evaluated hourly flow data for the period August 22 to September 16, 2000, which showed pulsing flows. The report speculated the cause or causes of pulsing flows, however, additional information could help better pinpoint the source. It is recommended that the following data be collected and evaluated, if available:
    - Hourly or daily *water elevation* records for all dams on the Millers River mainstem, Otter River Dam, and Tully Lake Dam. These data could be used to confirm which facilities are operating in a run-of-river manner.
    - Hourly or daily *discharge* records for all dams on the Millers River mainstem, Otter River Dam and Tully Lake Dam (broken down by turbine flow, gate flow, dam spillage, etc.). The discharge records would be used to determine if the dams are pulsing discharges.
    - Hourly or daily discharges for all NPDES facilities discussed in this report should be evaluated. Again, hourly or daily discharge data would be used to determine what effect discharges have on streamflow.

Overall, there needs to be a more coordinated operation of dams on the Millers Rivers and its tributaries to ensure that all pulsing operations are ceased.

- As noted above there are approximately 197 dams in the Millers River Basin. Some of these dams were constructed in the early 1900's for use as grist mills, sawmills, or textile manufacturing. Since many of these dams are likely abandoned and serve no purpose, consideration should be given to potential dam removal. This study did not consider the costs and benefits of potential removal. In most cases feasibility studies are conducted to determine the pros and cons of potential removal. River Restore in Massachusetts and the New Hampshire Department of Environmental Services in New Hampshire have been actively involved in dam removals in their respective states.

- As noted in Section 6.0, NPDES Discharges, there are two water treatment plant dischargers that were not evaluated in this study including Gardner Water Treatment Facility (MAG640041) and the Ashburnham/Winchendon Joint Water Authority (MAG640045). The initial evaluation focused only on the WWTP discharges. It is recommended that additional analysis of the water treatment plant discharges are warranted to provide a complete picture of flow releases to the basin. More specifically, hourly or daily discharge data from these two facilities are needed to evaluate the impact on receiving waters.

- As noted earlier, the Corps and USFWS are currently in the process of discussing the operation of Tully and Birch Hill Lake Flood Control facilities. These projects have the largest impact on the timing, magnitude, duration and frequency of flows in the East Branch Tully River and the Millers River below South Royalston. It is recommended that discussions continue and that the following flow-related issues be discussed: a) seasonal minimum flows, b) flushing flows, c) special whitewater releases, and d) ramping flows. The goal is to operate the facilities to mimic the natural runoff cycle, while preserving the purpose of these facilities to reduce flood flows.

- To facilitate salmon smolt migration to the ocean, downstream fish passage may be warranted at the L.S. Starrett facility (although the USFWS does not have authorization to require passage). Continuous downstream passage would then be provided between the stocking location and the Connecticut River.

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